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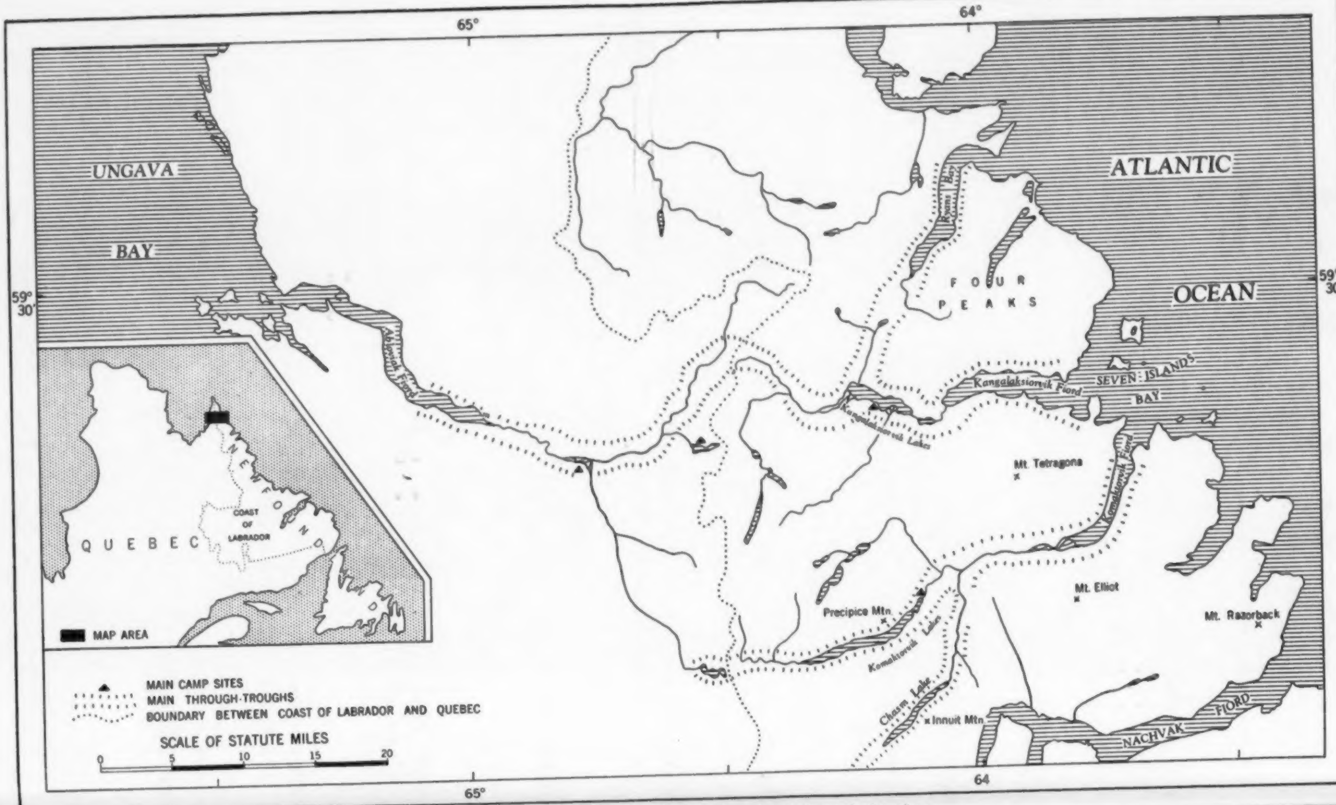
Cover Picture: Typical mountain scenery of the Komaktorvik lakes area, Northern Labrador. The camp lay beyond the low ridge in the middle distance. Mountains in background exceed 4,500 feet. Aug. 23, 1956. ***Photo: J. D. Ives***



Sketch map of Torngat Mountains, Northern Labrador.

GLACIATION OF THE TORNGAT MOUNTAINS, NORTHERN LABRADOR

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The writer, accompanied by his wife, Pauline Ives, as field assistant, worked in the Torngat Mountains of Northern Labrador between July 27 and September 16, 1956. The work was made possible by research grants from the Banting Fund, administered by the Arctic Institute of North America, and from the McGill-Carnegie Arctic Research Program. Transport from Goose Bay to and from the Torngats was generously provided by the British Newfoundland Corporation.

Upper Kangalaksiorvik Lake, some 15 miles west of Seven Islands Bay in latitude 59°22'N., was selected for the site of a base camp, and this was established with the aid of a Beaver aircraft on July 27. In addition, the Beaver was able to lay two food and fuel caches, one at the northeast end of Lower Komaktorvik Lake, and the other by the shore of a small lake on the Quebec side of the boundary, some 15 miles west of base camp. From these three centres an area of about 600 square miles, principally within the "Central Range" of the Torngats, was reconnoitred on foot.

Despite the short and relatively stormy season, it proved possible to complete a large part of the original program, although an investigation of the cirque glaciers was curtailed by the persistence throughout the summer of a considerable thickness of the 1955-56 snow cover on their surfaces. After August 20 this was augmented by frequent falls of fresh snow.

The following information is of a preliminary and reconnaissance nature, although it may be anticipated that future work will not greatly affect the general conclusions. The paper is based primarily upon a rapid review of the field notes and a cursory examination of the vertical air photographs from Saglek Bay northward to Cape Chidley. It is hoped that this work will be intensified and extended in the future. For information on the bedrock geology of the area the writer is indebted to Mr. Murray Piloski of the British Newfoundland Corporation.

Objectives of the field work

Two generally accepted, and yet untested, theories, which have played a fundamental part in the modern concept of the glaciations of Labrador-Ungava, and of northeastern North America as a whole, prompted the field investigations outlined below.

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In 1933, Odell, refuting the earlier work of Daly (1902), Bell (1882-84) and Coleman (1921), stated that the entire area of the Torngat Mountains had been completely inundated by continental ice at the Wisconsin maximum. Despite the slender evidence that Odell put forward, his concept, perpetuated by the writings of Tanner (1944) and Flint (1943 and 1947), has gained almost universal acceptance. Odell's main criticism of Coleman is based on the assumption that the felsenmeere so widely distributed above the 2,000- to 2,200-foot level were formed by frost action in post-glacial times.

Flint (1943, 1947, 1952 and 1953) has contributed extensively to the present understanding of the growth and disappearance of the Quaternary ice sheets. In considering the general climatic deterioration at the onset of glacial times, Flint envisaged the initial growth of vigorous glaciers in the coastal mountains of northeastern North America stretching from Labrador to Ellesmere Island. Flint states that the glaciers forming on these mountains would flow down their western flanks to accumulate as piedmont lobes and ultimately build up into an ice cap of continental proportions. During this growth the ice divide would move westwards from the mountains resulting in a reversal in the direction of flow across the mountains towards the east.

Flint pictured the reversal of these conditions towards the close of each glacial epoch, with the coastal mountains serving as the final centres of glacial outflow. This thesis apparently considers conditions in northeastern North America as the mirror image of those in northwestern Europe where the theory is based upon solid field evidence. Flint believed that the area west of the Torngats would prove of critical importance in the testing of this theory in the field, a belief which greatly influenced the general localization of this study.

The main objective of the present work was in general an attempt to establish the role of the Torngats in the glacierization of Labrador-Ungava, and in particular to assess the course of events in late-Wisconsin times with respect to the final disappearance of both continental and local ice masses.

Geological background

North of Nachvak Fiord the Labrador peninsula is composed of metamorphic and igneous rocks of Precambrian age. Between Nachvak Fiord and the Kangalaksiorvik lakes the main structural trend is north-northwest to south-southeast, roughly parallel with the coastline, and metamorphic zones of varying degrees of intensity follow this trend. Much of the bedrock is composed of various types of gneiss, a finely-banded garnetiferous gneiss and a granite-gneiss being particularly abundant. The rocks are predominantly coarse-grained and weather into a very rough surface upon which glacial markings are seldom clearly preserved, even on the lower ground which was cleared of ice most recently (Fig. 1). The entire area is cut by two series of basic dykes.

In the vicinity of the Kangalaksiorvik lakes the dominant structural trend swings round in a great arc and becomes roughly east-west on the Quebec side of the peninsula. Piloski has described this as a possible drag fold and

Fig. 1. Glacial striations and grooves in banded gneiss. The surface is relatively unweathered as it lies below high lake level. The glacial markings cross the lineation at right angles. Aug. 2, 1956.

it has an important influence upon the present relief. A major trough-like valley, passing inland from the head of Kangalaksiorvik Fiord, closely follows this trend, cutting through the height of land and passing westwards into Abloviak Fiord. Its highest point lies below 600 feet, although the surrounding mountains exceed 4,000 feet.

The major faults follow the dominant structural trend, although a second set, roughly at right angles to the first, is readily apparent in the topography.

Physiographic evolution

Until a more detailed examination of the available material has been made, the outline of the evolution of the Torngat Mountains given by Cooke (1930), and supported and extended by Odell (1933) and Tanner (1944), will be adopted as the most satisfactory. Very briefly this envisages the predominance of erosional processes over sedimentation since Precambrian times. In late Tertiary times the Labrador peneplain was uplifted to a considerable height and tilted so that a high escarpment bordered the Atlantic Ocean and the plateau surface sloped down gradually towards the west. This event has

profoundly affected the subsequent evolution of the area, and in this connection it is emphasized that in general the Torngat Mountains are not a mountain range in the true sense of the word, and that in particular there is no western flank, but merely a gentle plateau slope, which passes gradually beneath the water of Ungava Bay. The terminology of "Coastal Range" and "Central Range" proposed by Odell (1933) is therefore misleading and extremely unfortunate. Throughout this report, however, Odell's terminology is retained for the purpose of clarity when referring to different localities.

It is assumed that prior to the onset of glacial times the uplifted peneplain had been subjected to the processes of a fluvial cycle of erosion for a sufficient length of time to allow a late youth to early mature stage of dissection to develop. This created a very rugged mountain country bordering the Atlantic Ocean, grading westwards into a slightly dissected plateau.

This is an over-simplification of the true pattern of development, but little more need be added for the present purpose other than to emphasize that the late Tertiary uplift was by no means uniform, and that warping and faulting occurred, the results of which are clearly visible in the landscape today.

The precise number of glacial periods which have affected the area is unknown, and so far no stratigraphic proof of more than one glacial period has been found in Labrador-Ungava. It is assumed, however, that the sequence of events in the Torngats closely paralleled the developments which are comparatively well known in southern Canada and northeastern United States. Morphological evidence, in the form of valley-in-valley cross sections and the floors of glacial valleys trenched by deep water-worn gorges of presumed pre-Wisconsin age, was found in the Torngats to support this assumption. The evidence indicates that the present landscape owes its appearance to two and possibly three glacial and inter-glacial cycles.

The actual amount of erosion attributable to glacial action is a matter of considerable controversy, especially when viewed in the light of recent work (Battle, 1952; McCall, 1952; Boyé, 1950; Cailleux, 1952; etc.) much of which tends more and more to question the effectiveness of glaciers as agents of erosion. It is assumed that little or no erosion of the open plateau surface was accomplished by the passage of the continental ice. Thus Odell's designation of "glacial peneplain" (1933, p. 209) is not accepted. A considerable amount of vertical and lateral erosion was probably accomplished in the great through-troughs and valleys, where the ice was thick and the speed of flow accentuated by the topographical restrictions.

Fluvial erosion in pre-glacial and inter-glacial times, together with frost action and mass movement, and sub-glacial fluvial erosion, has probably produced more important results by volume of material removed than have the glaciers. The presence of the glaciers, apart from their active participation, has been necessary for the production of the characteristic "glaciated" appearance of the Torngat Mountains today. It is not enough to state that the glaciers are ineffective as agents of erosion; an alternative method must be proposed which will adequately account for the U-shaped cross section with truncated spurs, the over-deepening and production of rock basins and valley

steps, and the numerous other features so closely associated with "glaciated" mountains. Undoubtedly much more research is needed into the mechanisms of glacier flow and glacial erosion, but until conclusive evidence is forthcoming to the contrary the critical acceptance of the theory of glacial erosion seems advisable.

Fig. 2. Roches moutonnées and perched blocks in the Abloviak-Kangalaksiorvik trough, looking east. Kangalaksiorvik River and terraces in middle distance. Aug. 4, 1956.

The extent of the Wisconsin Glaciation

The discussion is restricted to a consideration of the Wisconsin Glaciation, first, because the pre-Wisconsin evidence is so far indistinguishable, and second, because the Wisconsin was probably the least severe of all the glacial periods so that the conclusions reached here can be regarded as minimal for the greatest extent of continental ice in Quaternary times.

Coleman (1921), and all workers before him (Daly, 1902; Bell, 1882-84) believed that the Torngats maintained a local centre of glaciation throughout Wisconsin times, that the penetration of continental ice from the west was limited, and that the higher summits, above about 2,500 feet above present sea level, remained as nunataks even at the height of the ice flood.

Coleman's argument is based largely upon the sharp forms of the upper summits, which he believed would not have withstood inundation by continental ice, and upon the presence, on the higher surfaces, of a heavy mantle

of frost-riven bedrock, or felsenmeere, which he considered to be of pre-Wisconsin age. Odell (1933), on the other hand, argued that the felsenmeere were formed in post-glacial times by vigorous frost-shattering, which thus invalidates Coleman's conclusion, and, despite the intensity of frost action, Odell found evidence of glacial polishing and grooving at an altitude of 4,700 feet.

Apart from the theoretical challenge by Dahl (1946 and 1947) who suggests that the coastal summits above 3,000 feet must have remained as nunataks on a consideration of the marginal surface slope of inland ice sheets, the conclusions of Odell have remained largely undisputed (see, however, Mercer, 1956). Work in Iceland, where it was possible to prove conclusively that the high coastal mountains remained as nunataks throughout the glacial epoch, induced the writer to consider carefully the objections of Dahl, and to attempt to re-assess the field evidence before making a final conclusion.

Thirteen of the major summits in the "central" Torngats, between Chasm Lake and Upper Kangalaksiorvik Lake, were ascended and their surfaces were subjected to minute examination. In addition uncounted spot examinations were made for evidence of glacial action throughout the area studied. From this two important generalisations can be made. First, in the eastern sector, between Mount Tetragona and the Quebec boundary, there is a marked contrast between surfaces above and below the 2,000- to 2,200-foot level. Below this level evidence of widespread glaciation, as noted by Coleman

Fig. 3. Boulder fields of glacial moraine from which the fines have been washed by melt water. Altitude about 1,500 feet. Aug. 2, 1956.

Fig. 4. Frost-riven bedrock (felsenmeere) on summit of peak in "central" Torngat Mountains. Altitude about 4,000 feet. Aug. 2, 1956.

(1921), is abundant, mainly in the form of erratic and perched blocks, glacial striations (Fig. 1), ablation moraine (Fig. 3), roches moutonnées (Fig. 2), and fluvio-glacial deposits. Above this level evidence of glaciation is almost entirely lacking. Second, on the western side of the Labrador-Quebec boundary where the mountains merge imperceptibly with the "Ungava Bay Plateau" conclusive evidence of glaciation was found up to a height of 3,000 feet above present sea level. Superficially it appeared that Coleman's interpretation, with this modification, was generally correct. Nor would it be expected that Odell's poorly preserved striations could have survived the vigorous frost action which he himself invokes to explain the formation of the felsenmeere in post-glacial times. This is especially emphasized when it is pointed out that the bedrock upon which Odell found indications of glacial striations was a finely-banded coarse-grained gneiss which weathers to produce coarse, north-northwest to south-southeast ridges and furrows, and a similar set at right angles along the cross jointing, all of which closely resemble poorly preserved striations, and on which it is impossible to distinguish glacial markings when in a weathered state.

Before proceeding further it is necessary to consider the weight of the evidence which is given to the presence of felsenmeere on the upper surfaces. Examination of the superficial cover throughout the Torngats revealed that,

Fig. 5. Perched blocks on glaciated summit of ridge above the confluence of Abloviak River with south bank tributary. Note the absence of frost-riven blocks. Altitude about 2,800 feet. Aug. 7, 1956.

excluding obvious till and fluvio-glacial deposits, there are two distinct types of boulder fields (felsenmeere). Below the 2,000- to 2,200-foot level the mass of boulders is characterized by a sub-angular to sub-rounded form (Fig. 3), although occasional boulders have been split subsequent to the rounding process. Above this altitude and away from talus slopes the surface cover of rock debris is distinctly angular (Fig. 4). The latter is described as true felsenmeere, the product of frost-shattering of bedrock, the former is believed to be ablation moraine from which all the fine material has been washed away by running water.

A further examination of the felsenmeere takes the argument to its conclusion. The summit ridge overlooking the junction of the Abloviak River with its main south bank tributary has two summit areas separated by a slight saddle, each about 2,800 feet above sea level. The ridge follows the east-west structural trend so that the composition of the bedrock of which the two summits are composed is identical—a coarse-grained gneiss. The eastern summit is a ridge of bedrock, littered with perched blocks, which have undoubtedly been deposited by continental ice (Fig. 5). In contrast (Fig. 6) the western summit is broad and level, about 600 yards across, and is covered with a deep mantle of frost-riven bedrock. Erratics were found among the

angular blocks. If the felsenmeere are truly of post-glacial age it is difficult to account for the relatively unweathered appearance of the eastern summit (Fig. 5). That this summit has been swept clean of superficial material, implies that, as the rock type is the same, its original cover of felsenmeere had been formed in pre-Wisconsin times and that it has been removed subsequently by the same agency that deposited the erratic blocks. The broader summit (Fig. 6), presumably because of a difference in local conditions, of which the areal extent is probably important, retained all or most of its cover of felsenmeere, which, however, may have been slightly reworked by the passage of ice.

The evidence already presented appears to invalidate the conclusions of both Coleman (1921) and Odell (1933), and the problem would have remained unsolved but for the eventual discovery of unmistakable erratic blocks (Fig. 7) on two of the major summits ascended, one at a little over 4,000 feet, and the other at the 5,000-foot level.

The general scarcity of erratic material on the higher summits must not be over-emphasized as, from a consideration of the morphology, the emplacement of erratics by continental ice flowing from lower land west of the Torngats would be a matter of some difficulty. Any erratic material found

Fig. 6. Felsenmeere on summit one-half mile west of summit in Fig. 5. Occasional large boulders probably emplaced from ice cover. "Ungava Bay Plateau" in background. Altitude about 2,800 feet. Aug. 7, 1956.

Fig. 7. Erratic block of granite-gneiss on summit in "central" Torngat Mountains. Altitude about 4,000 feet. Aug. 27, 1956.

at over 4,000 feet must have been dragged up in the bottom layers of the continental ice. This movement would need a vigorous flow of ice across the summits, which in turn implies that the summits in question were submerged beneath a considerable thickness of ice.

The morphology of the two mountains upon the summits of which the erratic blocks were found is interesting in this connection. Each summit is broad and level with a gently sloping west or southwest ridge. On one, which lies immediately north of Precipice Mountain in the Komaktorvik lakes area, the southwest ridge is broad and slopes gently from the summit, at a little over 4,000 feet, down to 2,700 feet. A trail of erratics was found from the 2,700-foot level all the way to the summit. The second summit is similar in form; it exceeds 5,000 feet, and lies immediately north of Chasm Lake. It is considered that such gentle slopes in the direction from which the ice came would be particularly favourable to the emplacement of erratic blocks, whereas it seems likely that steep onset faces would be inimical to this process.

The erratic material was of granite-gneiss composition and was found to be resting upon finely-banded garnetiferous gneiss. As the bedrock geology west of the Labrador-Quebec boundary is little known, this material may have travelled only a short distance, especially since granite-gneiss is a very common rock in the Torngat area. However, its presence was sufficient to indicate that continental ice had passed over mountains exceeding 5,000 feet and it is considered that the thickness of ice above the summit must have been of the order of 1,000 feet in order to promote the vigorous movement necessary for

the emplacement of the erratics. The erratics were relatively unweathered compared with the bedrock and felsenmeere upon which thy were resting, and it is assumed that they were deposited in post-Sangamon times.

From the evidence outlined above the following conclusions are put forward:—

1) The formation of felsenmeere pre-dates the Wisconsin Glaciation.
2) Fields of boulders of sub-angular to sub-rounded form below 2,000 to 2,200 feet are washed ablation moraines.
3) During the maximum of the Wisconsin, and hence during each preceding glacial period, the highest summits of the "central" Torngats were submerged beneath continental ice about 1,000 feet in thickness.
4) The maximum stage of inundation was relatively short-lived, and following this stage the higher summits stood as nunataks above the ice sheet for a considerable period.
5) A position of equilibrium was maintained for a long period when continental ice, which was flowing eastward through the great west-east troughs and diffluence passes, stood at the 2,000- to 2,200-foot level in the east, and up to 3,000 feet in the western slope of the "Ungava Bay Plateau" where the damming effect of the higher land caused the eastward-moving ice to be piled up to a greater height. During this period the local cirque glaciers would be very active, and the sharp, serrated ridges and peaks would receive their final etching.

The extent of the Wisconsin Glaciation on the coastal summits

So far the discussion has not included the so-called "coastal range" of Odell (1933) where summits of the Four Peaks group, Mount Tetragona, and southward, exceed 3,500 to 4,500 feet in close proximity to the present coastline. As no definite evidence of the glaciation of these summits was obtained, the discussion must follow the theoretical lines of Dahl (1946 and 1947).

Dahl objected to the conclusions of Odell (1933) and Tanner (1944) on the thickness of the Wisconsin ice sheet on theoretical grounds based on the measurement of the marginal slopes of present and past ice sheets. He suggested that the maximum slope of an ice sheet bordering a deep ocean would be 1:100, and upon this basis sharp coastal summits exceeding 1,000 meters within 100 kilometers of the margin of such an ice cap would remain as nunataks. Assuming the presence of a floating ice shelf, Dahl allows that the coastal summits could slightly exceed 1,000 meters and still fail to project as nunataks. Mercer (1956) has reiterated this argument and applied it to the southeast peninsula of Baffin Island as well as to the Torngat Mountains.

The first editions of the Canadian Hydrographic Charts, Nos. 4775 and 4776, published in 1955, clearly indicate that a broad continental shelf fringes the Northern Labrador coast, exceeding 100 miles in width in places. Eastward of the Torngats the shelf extends for 90 to 110 miles reaching a depth of 140-150 fathoms along its outer margin before dropping off steeply into very deep water. It is contended that the continental shelf would allow the accumulation of an enormous mass of ice, and if Dahl's marginal slope of 1:100

is applied to a continental ice sheet, the outer margin of which floats on the deep water bordering the shelf, such coastal summits as Mount Razorback would certainly be submerged, and it is most probable that the higher summits slightly farther inland would also be submerged, if only by a relatively thin cover of ice.

It is seen, therefore, that the evidence which supports the conclusion that the interior summits were covered by ice about 1,000 feet thick at the Wisconsin Maximum, suggests that the extreme coastal mountains were also submerged.

Directions of ice movements in the Torngats

The main movement of ice through and over the Torngat Mountains was from a westerly direction. As the bottom layers of the ice were strongly controlled by the topography, and as no striations were found on the summits examined, it has not been possible to give a more precise direction of movement than this. Although the trends of the striations in the valleys are, therefore, of limited value, they are instructive, as they provide, collectively with directional evidence gained from the examination of roches moutonnées, erratics, and fluvio-glacial deposits, a picture of conditions during the latter half of Wisconsin times.

As suggested above, it is envisaged that for a considerable period following the maximum extent of the Wisconsin ice sheet the higher summits projected as nunataks. During this time the pattern of movement clearly suggests that the Torngats were partially inundated by a great anastomosing system of glaciers flowing from an area to the west through every available trough, valley, pass and col, toward the Atlantic Ocean. This was slightly augmented by local ice supplied primarily from the numerous cirques.

Several interesting cirques were examined, and these showed every stage in the transition from a self-contained cirque with the backwall unbroken to an ice diffluence valley resulting from the progressive breaching of the backwall by a combination of cirque erosion and penetration by ice moving from the west.

It is emphasized that movement of ice from the west predominated except in the limited cases of local movement within the cirques. In no instance was there found any evidence of the reversal of flow toward the west from a theoretical local ice cap, and in only minor instances does the morphology of the western part of the Torngats coincide with westerly drainage. The three east bank tributaries of the main Abloviak tributary valley are broad and typical U-shaped valleys, which trend roughly east-southeast to west-northwest. The two largest valleys enter the main valley at grade, the third hangs some 800 feet above the floor of the main valley. Consideration of their morphology leads to the conclusion that at some period they contained westward flowing glaciers.

No moraines nor striations were found in these valleys, but even allowing the morphology of the valleys as evidence of local glacierization, and assuming

that these valleys contained glaciers in late-Wisconsin times, the glacierization was of very limited extent and does not invalidate the general conclusion that no major reversal of flow occurred towards the close of Wisconsin times.

Examination of the movement of erratics was made in detail in certain limited areas. For example, all anorthosite erratics were found eastward of their parent outcrops. The same conclusion was drawn from an examination of the eastern margin of the north-south zone of garnetiferous gneiss which extends from Nachvak Fiord to the Kangalaksiorvik lakes. Lack of clear differentiation between the various rock types of the metamorphic zones did not allow further expansion of this method in the time available. Occasionally blocks of crystalline quartzite were found in the Kangalaksiorvik-Abloviak trough and below the Komaktorvik lakes; these may have been derived from the outcrop of crystalline quartzite shown on Piloski's map northwest of the head of Upper Komaktorvik Lake. If this is so it suggests a circuit movement of the bottom ice conditioned by the major topographic forms. Blocks of a pudding stone conglomerate were found along the floor of the main south bank tributary of the Abloviak River. This rock was not found in situ and it is possible that it may represent blocks of indurated moraine.

Late-Wisconsin conditions

The predominance of the west to east direction of ice movement is significant in a consideration of the process of deglacierization of the Torngats. A series of critical localities, such as the thresholds of north-facing cirques tributary to major west-east valleys, the confluence of tributary valleys and the main through-troughs, and several of the main ice diffluence cols, was selected and studied in an attempt to assess the extent of any late-Wisconsin resurgence of local movement once the main ice streams from the west had disappeared. All the evidence suggests that such a resurgence did not occur, and that the final movement of ice was from the west. This was illustrated by an examination of the threshold of the cirque on the north face of Mount Tetragona which contains Bryant's Glacier. The present snout stands at about 1,400 feet above sea level and below it three morainic arcs extend northwards; the terminal moraine, lying at about 1,100 feet above sea level, is situated almost one mile north of the snout. This moraine probably marks the historical maximum of the glacier, although it may possibly represent a late-Wisconsin stage.

The cirque opens out into a major U-shaped valley which cuts from southwest to northeast through the Tetragona mountain group. Clear evidence was found in this valley, in the form of erratics, roches moutonnées and striations, that the final movement of ice was towards the northeast, and striations were found within 100 yards of the terminal moraine of Bryant's Glacier. Thus it is apparent that in late-Wisconsin times the cirque glacier was not sufficiently vigorous to extend beyond the limit of its own cirque. Similar evidence was found throughout the area and indicates the insignificance of a late-Wisconsin outflow of ice from the Torngats.

This was further substantiated by the presence of lake shorelines in valleys tributary to the main through-troughs, indicating that ice-dammed lakes existed in the local valleys while continental ice still remained in the main valleys. A well formed shoreline was observed in the south bank tributary of the Abloviak Valley extending six miles upstream at an altitude of almost 600 feet above sea level. A series of perched deltas, subsequently dissected, were found on each side of the valley and coincided with the shoreline (Fig. 8). Subsequent lowering of the trunk glacier in the Abloviak Valley appears to have been gradual as no lower shorelines nor perched deltas were found. It is clear, however, that in the main valley, once the divide area had emerged from the ice, a second lake was formed to the west of the divide which spilled over eastwards into the Kangalaksiorvik River.

Fig. 8. Dissected perched delta and glacial lake shoreline in south bank tributary valley of the main Abloviak-Kangalaksiorvik trough. Aug. 10, 1956.

Examination of the aerial photographs reveals the presence of lake shorelines in other parts of the Torngats. Mr. Piloski and Dr. E. P. Wheeler 2nd have informed the writer that similar ice-dammed lakes were formed in the Saglek Fiord-Korok River area farther south.

Fig. 9. View towards the northeast from peak in "central" Torngats. Four Peaks group on the right, Ryans Bay in distance and Upper Kangalaksiorvik Lake to right of centre. Aug. 2, 1956.

For the present no definite chronological correlation between the lake shorelines, overflow channels and marginal drainage channels can be attempted. However, the main lines of the deglacierization can be envisaged.

Following the emergence of the summits as nunataks the Torngats remained in a stage of partial submergence for a considerable period. With the general climate amelioration that heralded the close of Wisconsin times the snowline in Labrador-Ungava gradually became higher. A critical height would be reached after which a relatively slight vertical movement would lift the snowline above a vast area of the ice cap, and in a very short time the entire ice cap would become climatically dead. Thus the early stages of thinning would be gradual but the final stage would result in rapid thinning of the glaciers and the ice sheet itself. At this stage it is believed that the main trunk glaciers were still of the order of 2,000 feet in thickness and continued their flow towards the east for some time. Progressively the supply of ice would diminish and they would eventually melt in situ, the floors of the deepest valleys being the last areas to be free of ice.

This condition is clearly seen in the Komaktorvik-Chasm lakes area where sub-parallel marginal drainage channels sloping gently down valley can be traced from an altitude of about 2,000 feet down to the valley floors. The average vertical interval between the channels is about 15 feet, and if, as

maintained by Mannerfelt, they are annual features, the final wastage of the 2,000 feet thick Komaktorvik and Chasm glaciers appears to have been completed in less than 150 years, but this does not allow for temporary climatic fluctuations.

This phenomenal rate of disappearance of ice and the production of huge volumes of melt-water are in accordance with the evidence that below the 2,000- to 2,200-foot level the land has been thoroughly washed by strong melt-water torrents.

Fig. 10. Cirque with small glacier between Chasm and Komaktorvik lakes. Note that the backwall has been partially breached. Summits exceed 4,800 feet. Aug. 27, 1956.

Typical dead-ice topography in the floors of the main valleys indicates the location of the final ice remnants—at those places where the ice reached a maximum thickness in Wisconsin times and where the supply from the west was probably the most vigorous.

Finally, it is probable that when the deglacierization was complete the cirque glaciers also melted away, and that the present diminutive cirque glaciers have developed since the post-glacial Thermal Maximum, that they reached their maximum historic extension between 1600 and 1850 A.D., during the so-called "Little Ice Age", and at present are possibly just emerging from a period of rapid recession.

Following the emergence of the land from the Wisconsin ice masses a marine transgression occurred, reaching a minimum height of 205 to 225 feet above present sea level. The assumption that the original depression, due to the thickness of the ice load, and hence the subsequent recovery was greatest in the west is supported by scattered pieces of field evidence. Old river terraces in the Abloviak Valley were seen to be inclined gently towards the west, that is, in a down-valley direction. Mr. Piloski has also described a lake shoreline above Nakvak Brook, which drains into the northern arm of Saglek Bay, to be inclined towards the west.

Fig. 11. Small cirque glacier, now stagnant, near head of Abloviak Fiord. Ridge above ice raises to 2,800 feet above sea level. Aug. 9, 1956.

The role of the Torngats as a possible centre of ice dispersal

From the evidence presented above it appears that in late-Wisconsin times no centre of ice dispersal existed in the Torngat Mountains. Before the possible role of the Torngats in the initiation of the Wisconsin ice sheets can be considered, the physical character of the area must be re-emphasized.

Flint (1943) tends to regard the Torngats as a mountain range, and if this were the case then his theory of the initial accumulation and dispersal from such a range would be logical. As has been stated above however, Odell's terminology of "Coastal" and "Central" *ranges* is especially unfortunate as the Torngats are merely the dissected eastern edge of an uplifted and tilted

Fig. 12. Cirque development in "central" Torngats. Aug. 27, 1956.

peneplain. Above all, the western slope is extremely gentle and any such description as "western flanks" is erroneous. Furthermore, a vast area of the Labrador-Ungava plateau exceeds 2,500 feet in altitude, which, when considering the areal extent and position in relation to the source of precipitation, is much more significant as an initial accumulation area than are the Torngats.

Preliminary investigations of the snowline in Labrador-Ungava, after the style outlined by Professor Gordon Manley in England (1949), also lend support to this concept. Semi-permanent snow beds in the Knob Lake area at an altitude of 2,000 feet above sea level allow a rough estimate to be made of the present height of the snowline above the land surface. This is approximately 2,000 feet, or 5,000 feet above sea level. In the Torngats the permanent snowline lies at about 3,500 feet. Widespread lowering of the snowline across Labrador-Ungava, resulting from progressive climatic deterioration at the onset of glacial times, would rapidly place an immense area of the plateau above the snowline, and hence form a huge reservoir of névé long before any significant accumulation could occur in the Torngats. Although many more data are needed, it is concluded that at the onset of Wisconsin times glacierization across a large area of the Labrador-Ungava plateau would have been instantaneous at the time of any significant lowering of the snowline. Furthermore, although small glaciers would develop concurrently in the Torngats, the build-up of an ice cap on the plateau to the southwest would starve them of precipitation and the first major glaciers would move from the west and southwest through the mountains to the Atlantic Ocean.

Fig. 13. The north face of Mount Tetragona, 4,500 feet, with the deep cirque that contains Bryants Glacier. Moraine with kettles in foreground. Sept. 1, 1956.

Conclusions

1. The highest summits of the Torngat Mountains were completely submerged by eastward moving continental ice at the height of the Wisconsin Glaciation. The ice reached a thickness of possibly 1,000 feet above the "central" summits and the highest coastal summits were probably covered by at least a thin cover when the ice margin reached the vicinity of the outer edge of the continental shelf, some 90 to 100 miles east of the present coastline.

2. Local glaciers in the Torngats never reached significant dimensions, and in late-Wisconsin times most cirque glaciers did not overspill the cirque thresholds.

3. The final movement of ice, excluding the local movement within the cirque, was from the west, and during the final stages of the Wisconsin Glaciation there occurred the rapid melting in situ of thick masses of ice.

4. Two, possibly three, separate glacial periods are recognized from the morphology of the area.

5. Instantaneous glacierization of a large area of the Labrador-Ungava plateau is considered the most likely method of initiation of a continental ice sheet in northeastern North America at the onset of each glacial period.

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Fig. 1. Ice fog at Eielson AFB, Alaska. Jan. 3, 1954.

ICE FOG AS A PROBLEM OF AIR POLLUTION IN THE ARCTIC

Elmer Robinson, William C. Thuman, and Ernest J. Wiggins*

THE term "arctic" frequently evokes an image of vast expanses of ice and snow and rock and tundra, with widely separated and sparsely populated settlements, where many of the normal problems of community life in the temperate regions are unknown. Whereas this picture may be generally true in respect to small, relatively static settlements, the rapid growth and development of larger communities, such as Fairbanks, Alaska, have brought with them many of the problems inherent in typical industrial communities throughout the world. Air pollution is one such problem. Air pollutants may be solid, liquid, or gaseous, and are usually produced by domestic and industrial heating plants. If certain meteorological conditions and topographical features combine, these products of combustion are held in suspension in the air and increase in concentration until troublesome effects occur. In many communities in the Alaskan and Canadian Arctic, air pollution during the winter months manifests itself primarily as ice fog. These fogs are troublesome because they frequently reduce visibility sufficiently to hamper both aircraft and automobile operations.

Winter fogs of natural origin have been reported frequently, and have been called "ice crystal fogs," "frost smoke," "sea smoke," "arctic ice smoke," "arctic sea smoke," and "smoke frost" by various observers. Petterssen (1940) attributed the formation of "ice crystal fogs" to a process of sublimation of atmospheric water vapor on sublimation nuclei beginning at temperatures of about -20°C, and he said that at still lower temperatures (-30 to -50°C), ice crystal fogs are a common occurrence in regions such as Siberia and Northern Canada. He also describes the cloud to be of such density at extremely low temperatures that it appears as a thin mist or haze ("frost haze"). Frost (1934) describes winter fogs as a disagreeable feature associated with extreme cold. He reports that at Fairbanks, temperatures of -45°C or lower are always accompanied by dense fog. For example, during January 1934 there were 348 hours during which the temperature was -45°C or lower. Of the 348 hours, 320 hours were accompanied by dense fog. On one occasion, the fog prevailed for 155 consecutive hours. This was undoubtedly the same type of ice fog as that studied in the present program.

The earliest report of ice fog, which the authors found in the literature, is in Nansen's narrative of the 1893-6 voyage of the *Fram* (Nansen, 1897).

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He observed that at very low temperatures (evidently below -40°C) the *Fram* always gave off a mist, which was carried downwind.

General Aspects

Water vapor is not thought of as an air pollutant in the usual sense, that is, a product of human activity that produces loss of visibility or other deleterious effects when released into the atmosphere. Whereas water fogs are a serious handicap to air operations, ocean shipping, and land traffic in many localities, they are primarily of natural origin and aggravation of the situation through human activities is usually caused by providing additional condensation nuclei rather than water.

At temperatures below 0°C conditions change considerably. For example, at -40°C the amount of water vapor in the air at saturation is only 0.12 gm./m.^{3}, as compared with 4.8 gm./m.^{3} at 0°C, a ratio of 40 to 1. Once saturation is reached the additional amount of particulate water required to reduce the visibility to a restrictive value such as 400 meters is very small, of the order of 0.05 gm./m.^{3}. Furthermore, the turbulence of the lower atmosphere usually decreases with falling temperatures so that the volume of air that must be saturated to produce fog becomes smaller at lower temperatures. In addition, wind speeds are mostly quite low at inland localities in very cold weather, and the distribution of surface temperatures tends to confine any material that is emitted near ground level to a layer not more than 10 to 20 m. thick. Added to the factors that reduce the quantity of water vapor required to form a fog is the increase in the rate of production of water vapor that usually occurs when air temperatures fall. The then necessarily more intensive heating causes a higher consumption of fuels and, because of the hydrogen in the fuel, large quantities of water are produced when they are burned. For example, the combustion of one gallon of gasoline results in the production of approximately one gallon of water. Obviously, at most localities, when the temperature falls, there is a rapid increase in the probability that the air exceeds the saturation point in respect to water vapor in the vicinity of human activities.

The ice fog problem encountered at most centers of population, including military installations, at inland localities in the arctic is a good example of the situation just described. Particular difficulties with ice fog have been encountered at the United States military installations of Ladd and Eielson Air Force Bases in the Fairbanks, Alaska area. Stanford Research Institute was engaged by the Air Force Cambridge Research Center to investigate the problem. The study included an initial, short-term field program in the winter of 1952, and extensive field programs in the same area during the winters of 1952-53 and 1953-54. Field investigations were conducted primarily at Eielson Air Force Base, where a laboratory was established near the main runway. Additional observations were made at Ladd Air Force Base, and in the city of Fairbanks. Studies to augment the field investigations were conducted at the laboratories of Stanford Research Institute in Menlo Park, California.

The ice fog situation observed in this program is probably typical for most centers of activity in the Alaskan and Canadian interior, while at coastal locations a different situation is to be expected. At these latter places wind speeds and temperatures are generally higher, the influence of artificial water vapor sources is reduced, and ordinary sea fog is often observed. The present investigation is limited to the inland type of low-temperature fog, which is characteristically "ice fog."

In general, the ice fogs observed during the field investigations were shallow with well-defined upper limits. Fig. 1 shows a clearly defined ice fog from a distance. This fog covered the air field at Eielson AFB. On some occasions stratified fog layers were observed. The horizontal extent of the fogs typically coincided with the areas of human activity, including the well-travelled road outside the built-up areas, although during prolonged periods of cold weather the area covered by fog gradually increased. On at least one occasion a 20- to 30-mile section of the Tanana Valley became filled with fog after a week of temperatures in the vicinity of -40°C.

The study of the ice fog problem proceeded along two general lines: (1) the physical-chemical characteristics of the fogs, and (2) the meteorological conditions accompanying their formation and disappearance. The constituent particles of the fogs were studied first by conventional collection methods such as settling and filtration. It was demonstrated at an early stage that the principal reduction of visibility at Eielson AFB resulted from water or ice aerosols, with little contribution from soot, fly-ash, or other non-aqueous materials. This may not always be true in a city such as Fairbanks, where a considerable amount of low-grade bituminous coal is used for domestic heating. The presence of numerous sources of ice fog in the city of Fairbanks is evident in Figure 2. Most of the sources are heating plants in residential and business buildings.

The Fog Aerosol

The ice fog has most of the visual characteristics of water fog, and seldom shows optical evidence of the presence of crystals. It has been stated by George (1951) that ice fog is composed of ice crystals, but we know of no previous studies describing the crystal forms of the particles of the fog aerosol.

During the studies in the Eielson area the method used most frequently for examination of the fog particles was simple settling on microscope slides. The collected particles were either viewed and photographed directly by using a microscope and camera located outdoors, or plastie replicas were prepared for permanent records by the Schaefer technique (Schaefer, 1941).

These studies showed that the ice aerosol had the following general characteristics. At temperatures above -30°C, the aerosol particles consisted principally of well-developed hexagonal plates and prisms such as those shown

Fig. 2. Ice fog over Fairbanks, showing domestic heating sources.

in Fig. 3. The ice crystal aerosol observed in the absence of fog at various temperatures consisted also largely of hexagonal crystals of this nature. At temperatures below -30°C, when ice fog began to appear, an increasing proportion of small, nearly spherical particles was observed (Thuman and Robinson, 1954a). Fig. 4 is a typical example of this ice fog aerosol. At temperatures of -40°C and below, the fog normally consisted almost exclusively of such particles. For convenience the authors labeled these particles "droxtals." The name seemed descriptive since they appear to be frozen water droplets with only rudimentary crystal faces, as seen at higher magnification

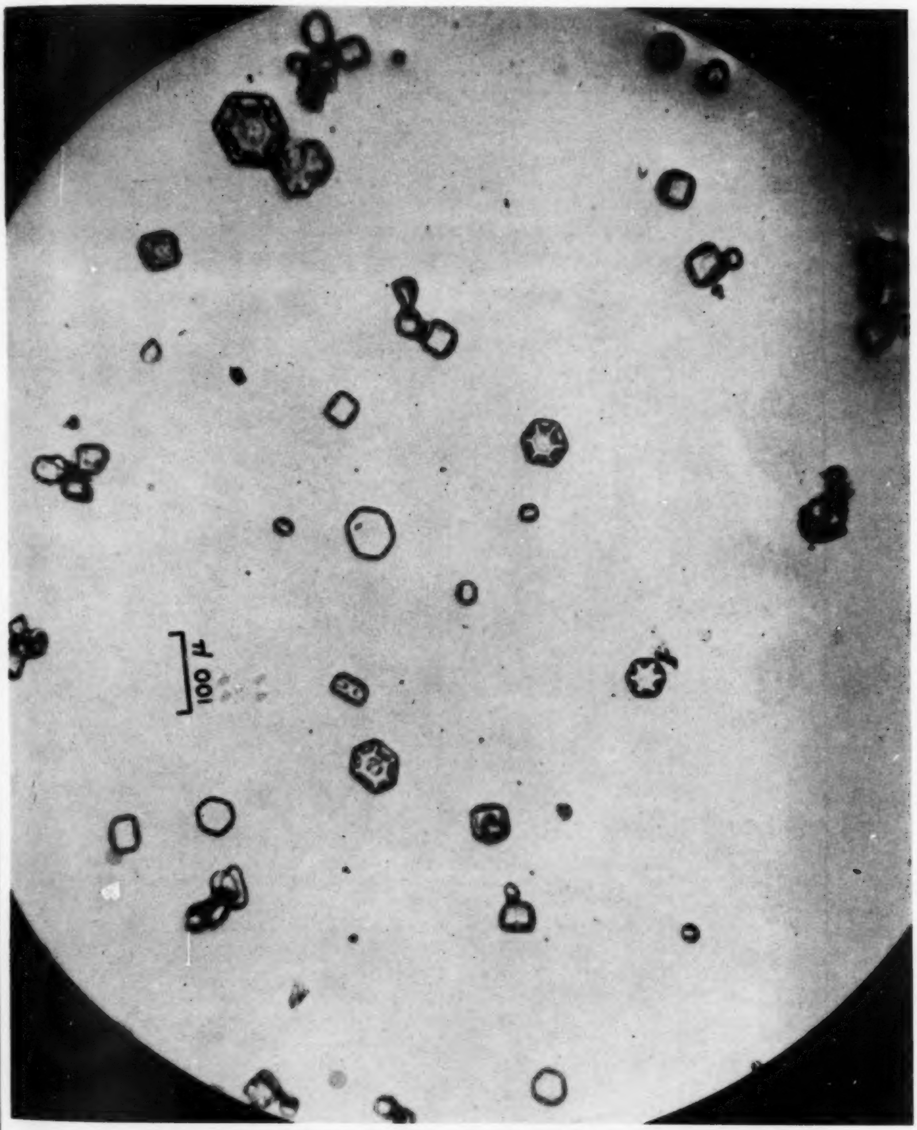

Fig. 3. Ice crystals collected at -27°C, visibility 20 miles.

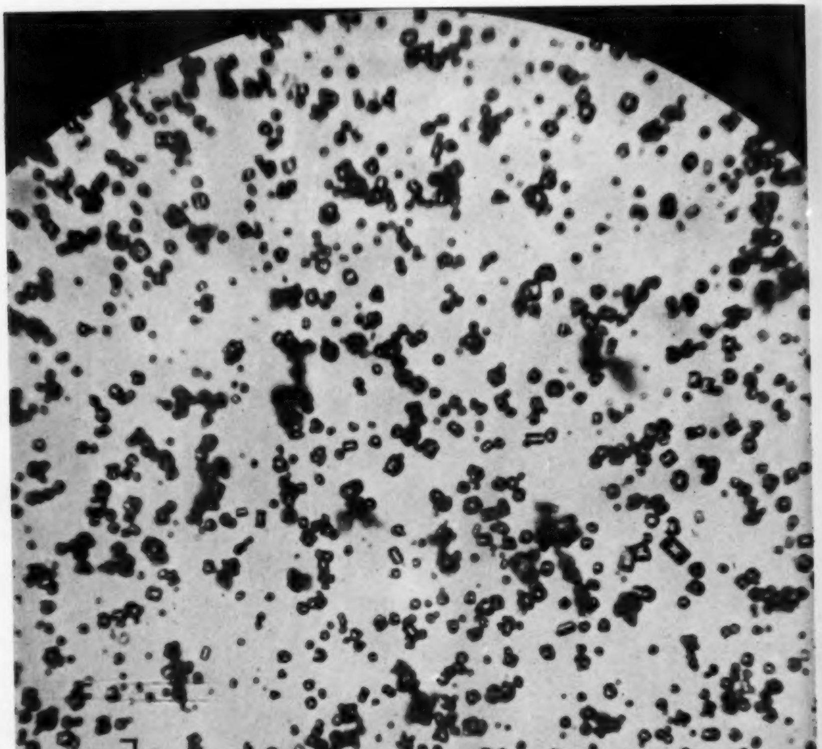

Fig. 4. Particles collected in ice fog at -41°C, visibility ¼ mile.

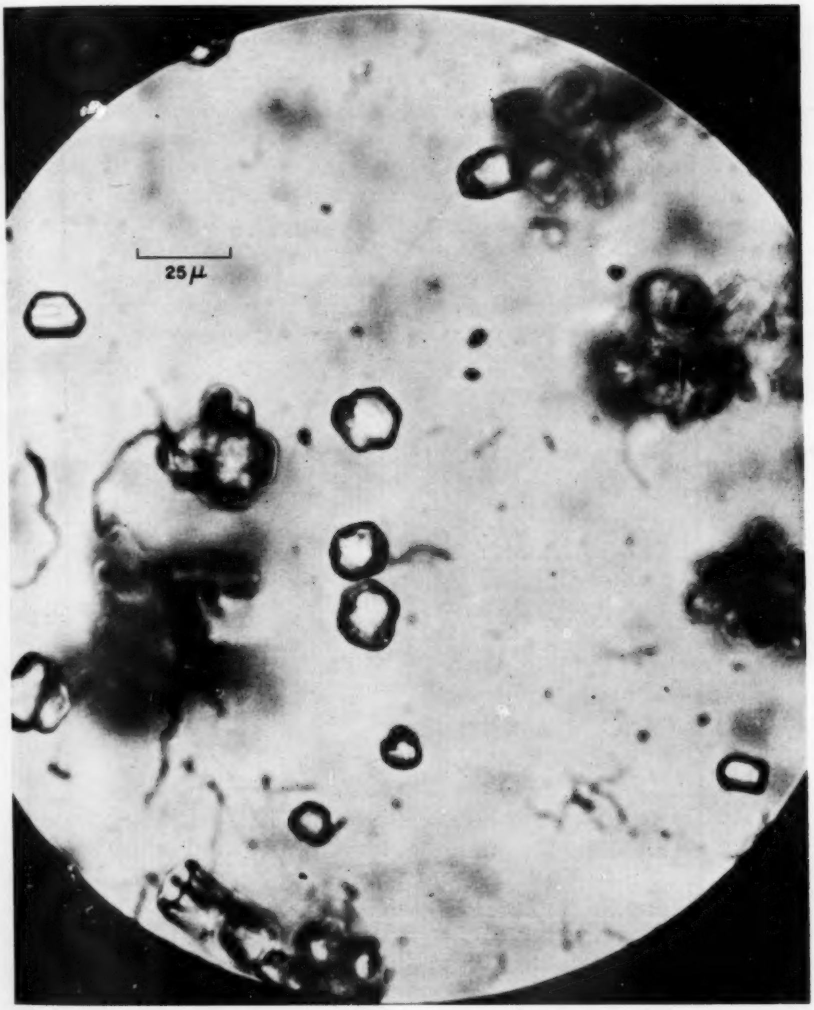

Fig. 5. Ice fog particles, -39°C, visibility ¼ mile. Febr. 25, 1954.

in Fig. 5. Since no more apt terminology was found in the literature the name droxtal has been retained for these particles. The droxtals appear to be the constituent which gives a low-temperature ice fog the typical dull gray appearance and causes the reduction in visibility. The larger, well-developed crystals that are found at higher temperatures in the ice crystal aerosols produce the characteristic pillars and other optical effects but cause little reduction in visibility. Fig. 6 shows the percentage distribution of ice particle types as a function of temperature. Note the rapid increase in droxtals at the lower

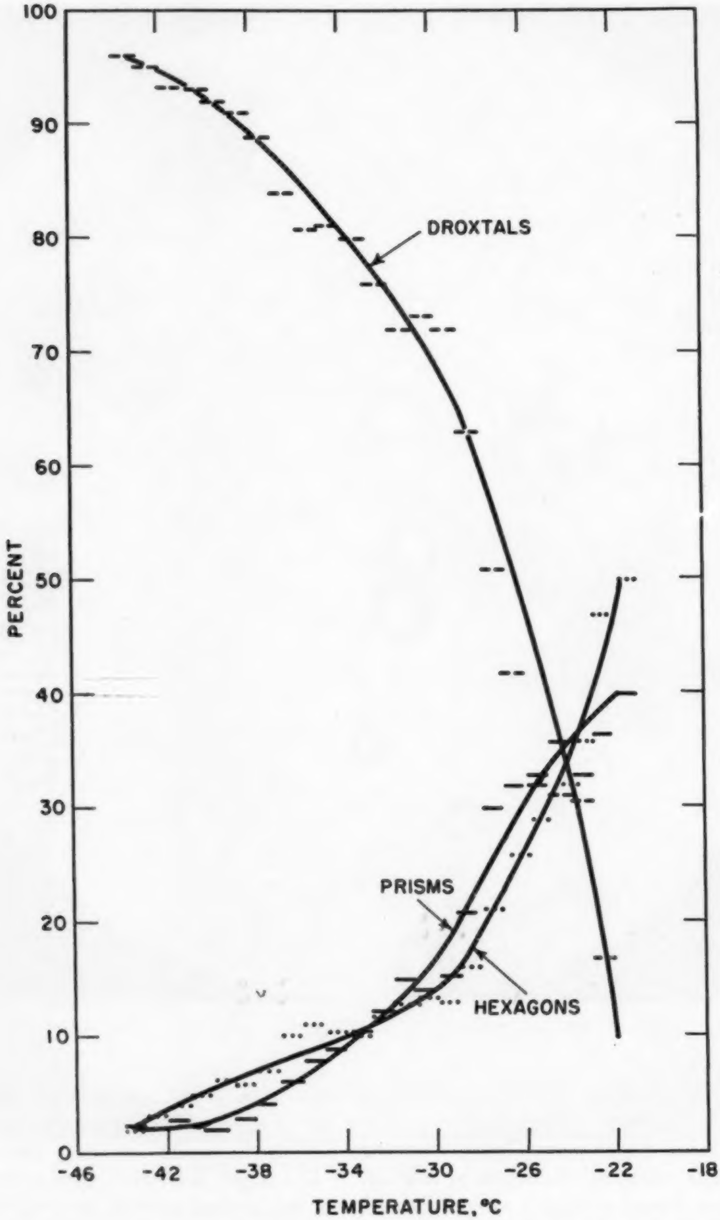

Fig. 6. Percentage distributions of ice particle types, Eielson AFB, Dec. 1953 to March 1954.

temperatures until at temperatures below -38°C droxtals account for over 90% of the particles.

After the droxtals were definitely identified as the major constituent of ice fog, the question arose whether the droxtals observed on the collection slides actually existed in the air as ice particles or were supercooled water droplets that froze on contact with the slide. This question was of some practical importance, since if the fog were supercooled water it might be possible to modify its properties by artificial addition of freezing nuclei. However, experimental seeding of ice fogs with dry ice and with silver iodide produced no observable changes, and suggested that the fog contained little, if any, supercooled water. Tests with a whirling wire showed no icing at the leading edge such as would be expected to occur if appreciable quantities of

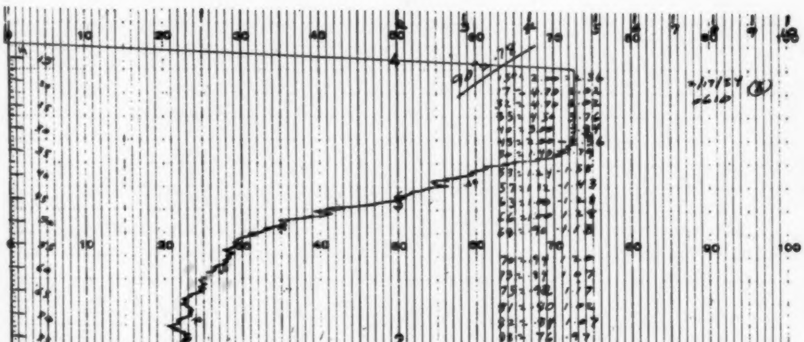

Fig. 7a. Typical scanning record of light scattering taken during an Alaskan ice fog.

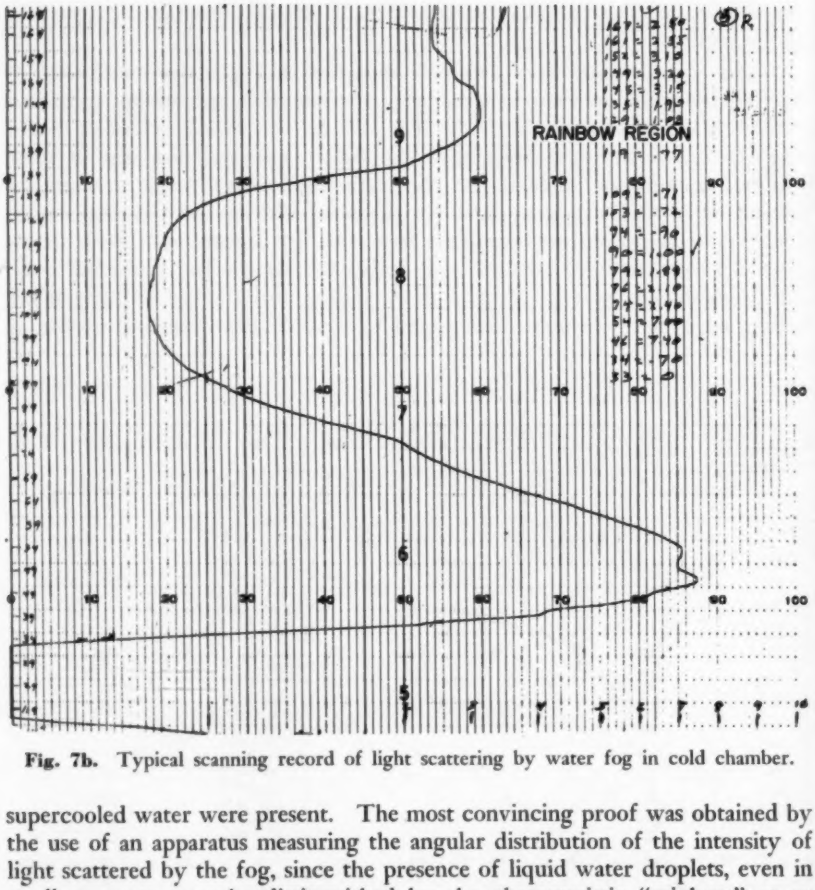

Fig. 7b. Typical scanning record of light scattering by water fog in cold chamber.

supercooled water were present. The most convincing proof was obtained by the use of an apparatus measuring the angular distribution of the intensity of light scattered by the fog, since the presence of liquid water droplets, even in small amounts, may be distinguished by the characteristic "rainbow" at an angle of 144° from the direction of the transmitted light beam (Thuman and Brown, 1954). Characteristic curves were obtained for ice fogs and water fogs produced in a cold chamber. Fig. 7a shows the typical intensity distribution curve for an ice fog in the field and Fig. 7b that for a supercooled water fog in the laboratory. No indication of the presence of water droplets is seen in the ice fog record, but the 144-degree rainbow is clearly indicated in the water fog curve.

Sources of Ice Fog

As a part of the research program attempts were made to identify the sources of water vapor responsible for ice fog formation, by making observations and taking photographs at ground level, by taking time lapse motion

pictures from vantage points above or outside the fog area, and by correlating wind direction and fog density at the field station. Low-level steam sources such as temporary heating plants, defective steam traps, kitchens, and so forth appeared to be major contributors to ice fog. The main power plant at Eielson AFB usually did not appear to contribute to the ground level fog, since the high exit temperature and velocity of the stack gases carried them to an altitude from which the water vapor did not return to ground level within the limits of the air base. This power plant plume is visible at the right in Fig. 1.

Vehicles appeared to make a substantial contribution to the fog at Eielson and Fairbanks, particularly since it was usual to let many engines run continuously during cold weather, even while the vehicles were parked. Many vehicles also carried auxiliary gasoline-burning heaters. The fog resulting from vehicle operation constitutes a special hindrance since it is concentrated on the roads and streets, which other vehicles must use. Aircraft engines also contribute large amounts of water vapor to the ice fog at an air base. This is not too serious during actual take-off, since the quantity of water vapor emitted per foot of runway is not great. However, when a number of aircraft engines are being warmed up prior to take-off large areas can become heavily obscured.

In cities such as Fairbanks a major source of water vapor appears to be domestic heating systems, as pictured in Fig. 2. Passenger cars and trucks produce local concentrations of fog on streets, particularly in downtown areas. No "natural" sources of ice fog were observed at any time in the Fairbanks area, although the writers were told that natural ice fog could be observed in places such as Circle Hot Springs where open water persists through the winter season. From the data gathered at Fairbanks and Eielson it appears that the prime contribution of the combustion processes is water vapor that is first condensed into droplets, then supercooled, and finally frozen into droxtals. In this process special nuclei are not necessary since the only nuclei required in the mechanism are the very common condensation nuclei.

Godson (1952) came to a similar conclusion about the influence of various settlements after a study of low temperature fogs in Canada. His data clearly showed that at Yellowknife, N.W.T., low-temperature fog at the observing station 5 miles from the town was closely associated with wind from the town toward the station. He concluded that the smoke from the town contributed water vapor and also nuclei active at the low temperatures. Godson mentions that low-temperature fog at Watson Lake is also closely associated with combustion processes in the settlement.

In addition to reports of ice fog associated with combustion in urban areas, there are frequent reports of ice fog over or near herds of caribou during very low temperatures. While no actual measurements have been made on caribou, it has been estimated that the breathing rate of a resting animal is 50-100 liters/minute and that of a trotting animal is twice that amount (Karstens, 1951). The deep-body temperature of the caribou is about 37°C, and the temperature of exhaled air about 32 to 36°C. The

exhaled air is probably saturated. On the basis of these estimates the breath of the animal contains about 3 grams of water vapor per 100 liters of air. A resting animal would thus exhale about 3 grams of moisture per minute and a trotting animal 6 grams per minute. Saturated air at a temperature of -40°C contains only 0.12gm./m.^{3}. Thus almost all of the 3 to 6 grams given off by the animal at air temperatures of -40°C will be precipitated in the form of ice particles. It seems therefore quite logical that a herd of caribou, whether resting or on the move, can create an ice fog when weather conditions are favorable.

Ice Fog Formation Mechanism

The process by which ice fog particles are produced from combustion gases and steam sources is apparently quite simple. The water vapor first condenses into small water droplets when the warm, moist gases are discharged into the cold atmosphere. An adequate supply of condensation nuclei is available at all times from the combustion of the fuel. At temperatures down to -30°C the supercooled water droplets are relatively stable and only a small number of crystals are formed. These crystals grow by transfer of water from the remaining droplets, forming comparatively large and well-developed crystals.

At temperatures below -30°C the effectiveness of most solid particles as freezing nuclei rapidly increases, until at approximately -40°C spontaneous freezing of water droplets occurs without the aid of nuclei. Below -30°C it may therefore be expected that increasing numbers of water droplets will freeze rapidly with little opportunity for growth in size or into crystalline structures and thus produce numerous small, nearly spherical particles. At intermediate temperatures a combination of these processes will occur.

Meteorological Conditions

As mentioned earlier, a program of meteorological measurements was carried out concurrently with the physical studies of ice fog. An instrument tower, 29 m high, was used for continuous recording of air temperature, vertical temperature profile, wind speed and direction, and net radiation exchange. The tower and its instrumentation are shown in Fig. 8. The instrument readings were recorded on a Brown 16-channel recorder coupled to a tape punch and programming unit. The perforated tape record consisted of readings of each channel at 4-minute intervals, together with time and scale range information. This record was subsequently transferred to IBM punch cards for machine processing of the data.

Vertical temperature profiles were measured by wiresonde soundings to heights up to 275 meters. Humidity profiles were measured by drawing air through polyethylene tubing carried aloft by the wiresonde balloon. Humidities were also measured at fixed heights by means of permanent tubing installations on the 28-meter instrument tower. The water content of the air was

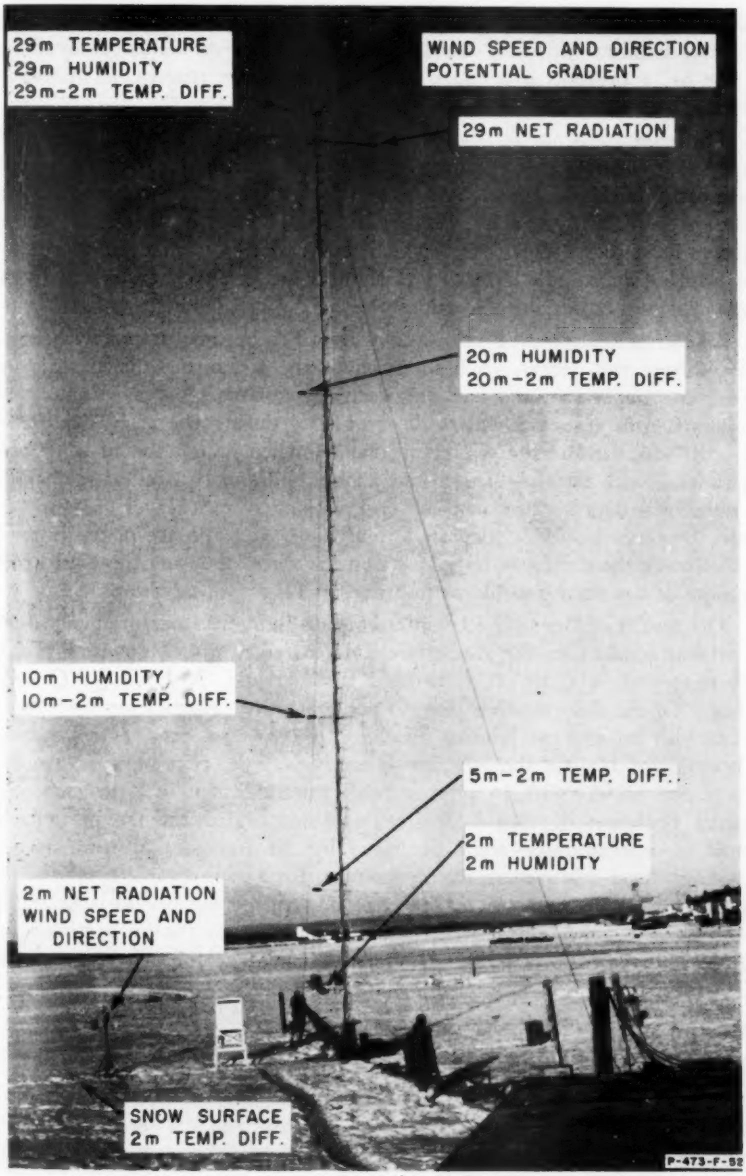

Fig. 8. Tower instrumentation.

determined chemically by drawing a measured volume of air through a methanol solution and then determining the amount of water removed from the air by a titration procedure using Karl Fischer reagent (Thuman and Robinson, 1954b).

The measurements of the temperature profile showed in general that steep, shallow surface inversions were present during clear, cold weather. These were modified, when ice fog began to form, so that the steepest portion of the inversion was just above the fog layer. The ice fog therefore occupied a generally stable surface layer, which was capped by an even more stable layer (Robinson and Bell, 1956). Surface winds were characterized by low speeds and highly variable directions.

The air at Eielson AFB was usually found to be unsaturated with respect to ice during the winter. Subsaturation of the air during the arctic winter is, of course, no rarity and has long been recognized. A very early attempt to quantify this situation was made by Hayes during the early explorations of north Greenland in the winter of 1860-61 when he conducted some crude experiments with strips of ice-coated flannel and small plates of ice. While his numerical data are missing, his observations were (Hayes, 1885): "The flannel becomes perfectly dry in a few days, and the ice-plates disappear slowly—while the thermometer is down in the zeros." Using the Karl Fischer technique it has been possible to improve on Hayes' observations.

The results of the 1952-53 winter season's humidity measurements during the present Alaskan ice fog studies are summarized in Fig. 9, covering temperature ranges of -4°C to -31°C in clear weather and -30°C to -43°C during ice fog. Of the clear weather runs, 95 per cent show unsaturation with respect to ice, with an average relative humidity of 83.6 per cent, and a standard deviation, s, of 12. Of the runs during ice fog, 79 per cent show unsaturation with respect to ice, with an average relative humidity of 91.1 per cent and a standard deviation of 11.8. As previously mentioned the ice particles are formed in supersaturated zones produced by the emission of steam or combustion products, and are capable of surviving for a considerable length of time in air that is somewhat below ice saturation. An ice fog period is terminated by the onset of conditions that favor the sublimation of the ice particles, such as higher temperatures or increased wind movement, which brings in drier air.

Summary

The ice fog aerosol results from the freezing of supercooled droplets, and as a result it is composed of irregular spheroidal particles. An ice fog appears to the observer to be very similar to a water fog. There is no rime ice accumulation. The ice fog particles are small enough so that their settling speed cannot be discerned in the open air. Accumulations of ice fog particles on exposed level surfaces resemble an "ice dust" rather than an accumulation of readily discernable particles as in the case of crystals. The ice fog is usually restricted in area and is associated with relatively large local sources of water vapor, almost exclusively man-made. Ice fog begins to form at temperatures

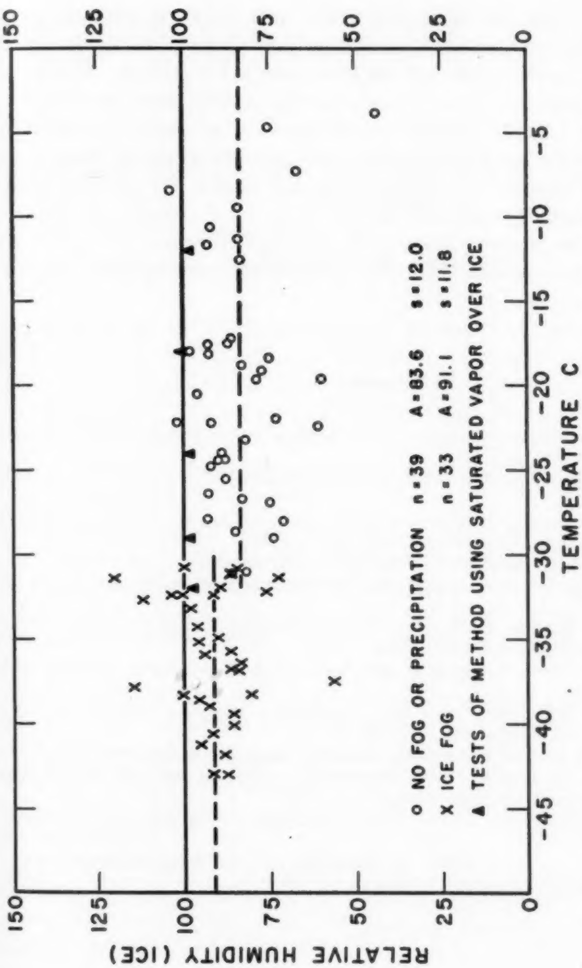

Fig. 9. Low temperature humidity determinations with use of Karl Fischer technique.

around -30°C and becomes increasingly probable when temperatures drop still lower. Because its source is the local discharge of water vapor, each area will exhibit its own pattern of formation. Spectacular optical phenomena such as halos and pillars are not characteristic of ice fog.

Ice fog is an example of an air pollution situation in which water vapor is the principal culprit. It appears to be an inevitable result of the emission of more than minor amounts of water vapor at low temperatures. Under these conditions only small amounts are required for saturation and the conditions in the surface layers of the atmosphere are such that only a relatively small volume of air needs to be saturated to produce fog. These conditions

are common in many areas in the Arctic. The only hope for alleviating the situation in communities where such conditions prevail in winter is to curtail vapor emission or to confine it to tall stacks in selected locations. While ice fog, as such, causes inconvenience to the general public only by reducing visibility, and is not a health hazard, its presence is an indication of local conditions which could equally well lead to the accumulation of other pollutants. If industrial expansion of Fairbanks or any similar area should occur in accordance with current hopes and desires of the local citizens, prospective industries as well as the communities should plan carefully to avoid future air pollution problems more serious than those at present resulting from ice fog.

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DEVELOPMENT OF YOUNG VARYING LEMMINGS (*Dicrostonyx*)

Richard M. Hansen*

On June 28, 1955 a female varying lemming (*Dicrostonyx groenlandicus rubricatus* (Richardson)) and her nine young were captured on the east side of Umiat Lake, Umiat, Alaska. The young were estimated to have been 3 days old. The female and her litter were kept in captivity for a period of 6 weeks in Alaska and later were transported to Fort Collins, Colorado. Four of the young survived, reproduced and established the laboratory colony upon which this study is based.

Owing to the various peculiarities that these animals possess, much interesting information can be obtained from the study of a laboratory colony. Animals of the genus *Dicrostonyx* are reputed to be the only rodents that molt into a white winter pelage (Anderson and Rand, 1945; Hall and Cockrum, 1953). Miller (1896) described their detailed morphology; Manning (1954) remarked upon reproduction, sex ratio, and life expectancy of these animals, both in nature and in captivity. Degerbøl and Møhl-Hansen (1943) reported upon breeding conditions and molting, and also included observations on the development of the young. Because some of the developmental features of the animals from Alaska were different from those reported by Degerbøl and Møhl-Hansen, and since so little is known about their development, it was deemed necessary to study the young in detail. Therefore, the captive colony was observed with the aim of obtaining data on growth and morphology. These would make possible a more accurate determination of the age of young animals collected in the field. In view of the fact that my animals were maintained under artificial conditions, the results should be accepted with some reservations, and confirmatory tests in both laboratory and field are needed.

I wish to express my appreciation to the Arctic Research Laboratory, Office of Naval Research, and to the Arctic Institute of North America for support of field work during the summer of 1955, and to Frank A. Pitelka, Museum of Vertebrate Zoology, University of California, under whose sponsorship my field work was conducted. He also read the manuscript of this paper and offered many suggestions. I should especially like to thank G. D. Hanna, then Director of the Arctic Research Laboratory, and his staff for assistance with preparations for field work.

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Materials and Methods. Observations were made on and data were obtained from several adults and thirteen litters; however, weight measurements are reported from only eight litters with a total of fifty-two young, produced by four different females. Mortality between birth and 40 days was approximately 20 per cent; that is, forty-one of the fifty-two animals survived to become 40 days old. Mortality was higher in the litters not included in the weight-growth measurements. The animals were kept in wooden boxes with open tops and dried beet pulp litter; cigar boxes were provided for nesting boxes, nesting material consisted of cotton and tissue paper. Food consisted of rolled oats, lettuce, cabbage, apples, and yams which were provided in adequate amounts at all times. When the young were from 17 to 20 days old, each individual was isolated in a single cage, although two young were occasionally housed together until they were approximately 30 days of age. Reproductively active males and females were housed individually as the females fight and males are often killed by females (See Manning, 1954).

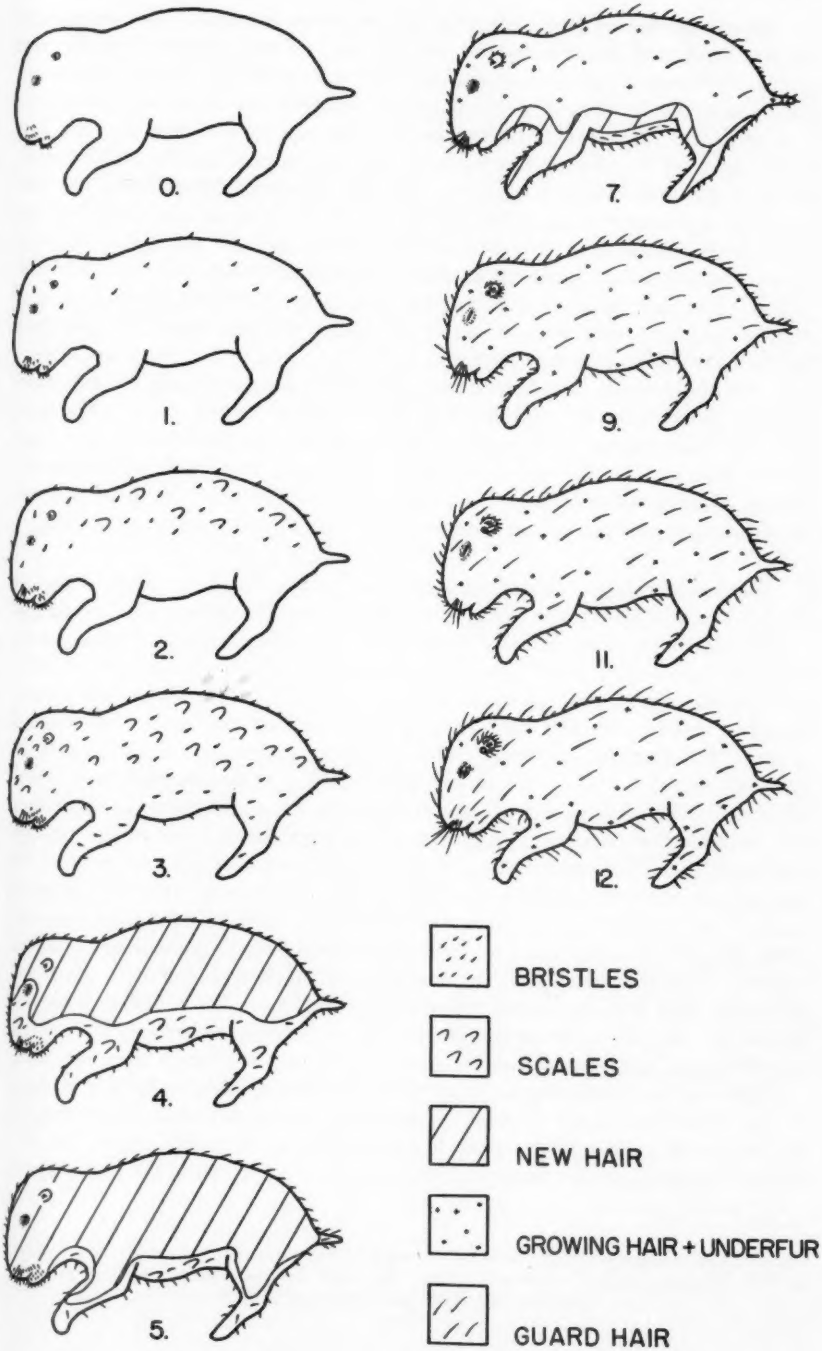
In the early stages of their development the young were weighed every second day, while during the later stages the weighings were less frequent. Behaviour and molt were studied during the periods when the young were taken out of the nest for weighing. After the young had left the nest, more time was devoted to observation of behaviour and development of hair and the changes in pelage were observed daily.

General Development

Newborn Animals. In newborn animals, the body is covered with loose, wrinkled skin. The dorsum is redder and more heavily pigmented than the remainder, which is pinkish. Short, black bristles are present on the lips, and vibrissae occur on the sides of the rostrum (see Fig. 1). Eight depressions are present on the belly surface indicating eight mammae (four pectoral, four inguinal). The toes are short, bulbous distally, and each is provided with a claw. The pollex is small and rudimentary. The tail is short and naked. The incisor teeth have not erupted. The eyelids are fused. The ears are small, obscure, and closed. When disturbed or when taken from the nest and laid on a smooth surface they attempt to right themselves; they lie, flexed ventrally, on either their sides or on the back. In the nest they are largely inactive and lie motionless, except when disturbed or nursing. The young are capable of vocalization immediately after birth. They possess a shrill, high-pitched voice that can be heard at a distance of at least 4 metres.

The weights of thirty-four newborn animals varied from 2.7 gm. to 4.8 gm. and averaged 3.8 gm. (see Fig. 3); the crown-rump length varied from 20 to 27 mm.

Fig. 1. The successive stages in the development of hair from newborn to 12 days of age. The figures give the age in days.


0.
1.
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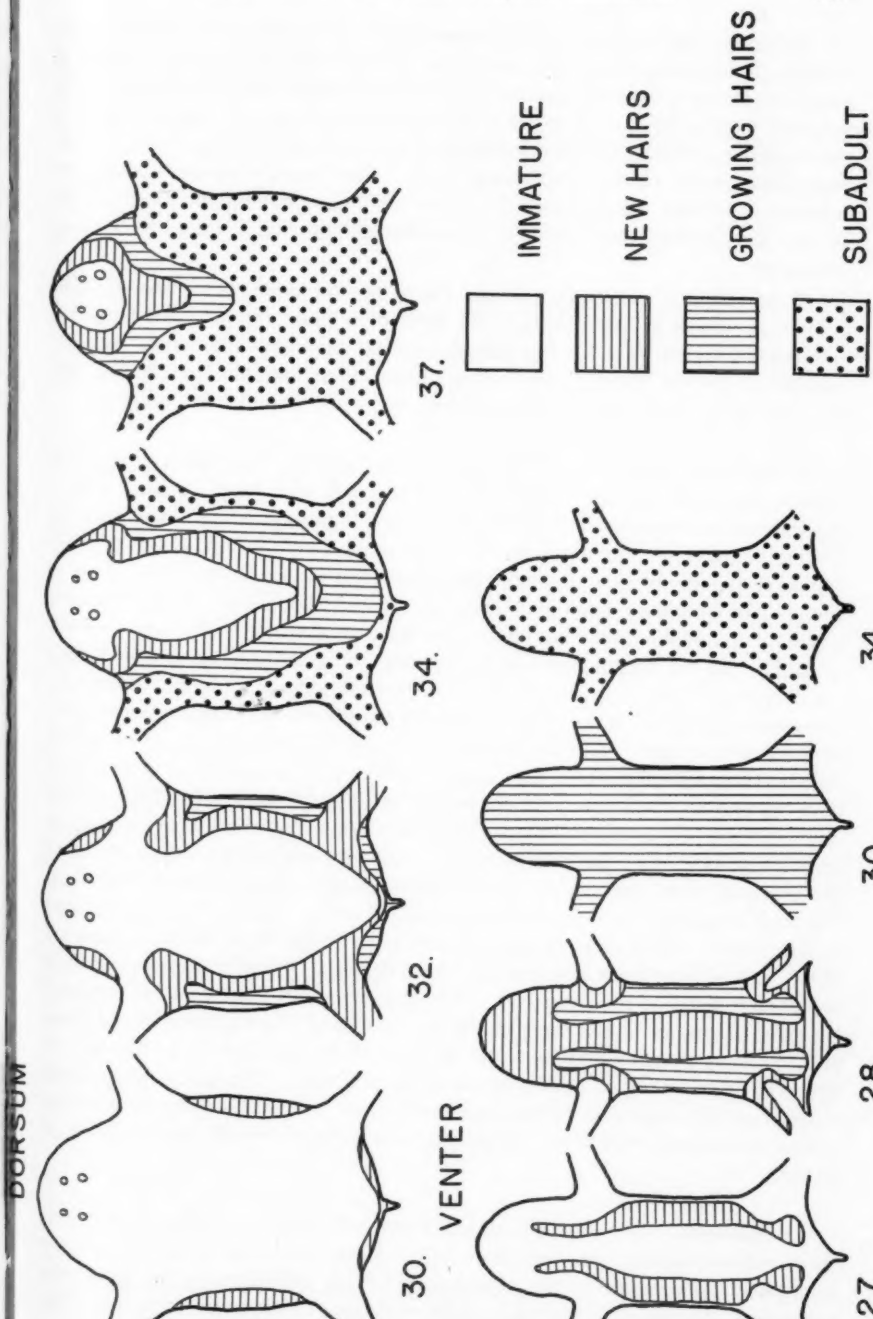
11.
12.
BRISTLES
SCALES
NEW HAIR
GROWING HAIR + UNDERFUR
GUARD HAIR

Development of Hair. Bristles become more numerous and are present on the head and dorsum on the second day. They spread ventrally and eventually cover all surfaces of the body by the third day. Scales appear on the dorsum on the second day and spread ventrally on the third and fourth days (Fig. 1). Pigmentation increases with age and by the third day the skin is darkened by developing hair follicles that lie beneath the skin. The mid-dorsal stripe area is especially dark. On the fourth day the young lose the wrinkled appearance of the skin and the tips of new hairs occur on the crown of the head and dorsum. The first hairs are bristle-like and the tips are banded with varied colours. Presumably these varicoloured hairs develop into "pile hairs". The new hairs spread ventrad in subsequent development and at 8 days of age the young are completely covered with hair, except on the areas between the legs. The dorsum is the first area to gain guard hairs and underfur. On the seventh day short, dense underfur is noted beneath the pile hairs and the guard hairs are slightly elongated beyond the pile hairs. The ears gain new hairs on the seventh day. The underfur and guard hairs grow and spread ventrad. At the age of 12 days the young have a dense, immature pelage. Hair growth continues beyond 12 days and by 15 days of age the pelage appears to have almost completed its growth and is harsh in texture.

Subadult Pelage. The first indications of the subadult pelage occur in animals that are from 26 to 30 days old (Fig. 2). The advent of new pelage is indicated by the appearance of short, stiff hairs beneath the immature pelage along the mammillary lines. The areas of eruption of new hair spread medially and dorsally from the mammillary lines. Two to three days after their initiation, newly erupting hairs have spread to all of the venter and dorsad to invest the shoulders and hips. The eruption and growth follow an anterodorsal direction. The crown of the head is the last area to gain new hairs. Some individuals may gain new hair even prior to the appearance of a molt line, but the molt line (if present) lags from 1 to 3 cm. behind the appearance of new hairs, and is not observable until the new growth is nearly completed. In this respect, the subadult molt is similar to the preliminary, and final autumn molts of the varying hare (Lyman, 1954: 404), in which the new hairs actually grow past the old, anchored hairs without removing them from their common sockets. The new hairs grow to nearly their full length and it is the large anchoring base pushing against the old anchored hair that actually dislodges the latter. The subadult pelage has usually completed its growth in 7 to 14 days following the first appearance of new hairs on the ventral body surfaces.

It would be interesting to know why the development of hairs at 4 days of age is initiated on the dorsum, whereas that of the subadult pelage begins on the venter. In adult varying lemmings the spring molt begins on the dorsum and develops in a posteroventral direction, whereas the fall molt begins

Fig. 2. The changes of pelage from the immature to the subadult. Average ages in days for the different stages of molt are given. The molt line is indicated by the junction between "subadult" and "growing hairs".


DORSUM
30.
32.
34.
37.
VENTER
27.
28.
30.
34.
IMMATURE
NEW HAIRS
GROWING HAIRS
SUBADULT

on the venter and is directed dorso-anteriorly (Degerbøl and Møhl-Hansen, 1943). This is essentially the same type of hair replacement that occurs in some subgenera of ground squirrels and other sciurids (Hansen, 1954). The subadult molt and fall molt of the varying lemming follow the same course of development, whereas the development of hair at 4 days of age has a pattern resembling more closely the spring molt. The harvest mouse (*Micromys minutus soricinus*) was reported by Kästle (1953) as having the same pattern of hair development and change in subadult pelage that I found in varying lemmings.

Coat colour is extremely variable and at present poorly understood. The colours of adults in my colony were similar to those reported by Degerbøl and Møhl-Hansen for the Greenland varying lemmings that they kept in captivity. In my colony the young varied from whitish to reddish, the majority being dark and similar in colour to young born in the summer.

Eyes, ears, teeth, claws. As growth and development proceed the eyes enlarge and open on the twelfth day. Degerbøl and Møhl-Hansen (1943) report that the eyes of the Greenland varying lemmings are not yet open by the twelfth day but are open by the fourteenth day. I have observed only one lemming in my colony whose eyes remained closed beyond 12.5 days of age, and its eyes were open at 13 days of age. Although the young are born toothless, the incisor teeth are observable beneath the skin of the gums on the third day; by the fourth they are puncturing the gums; and on the fifth they have erupted and are prominent. In captive lemmings from Greenland, Degerbøl and Møhl-Hansen report that the front teeth are hidden in the gums until 14 days of age. The cheek teeth are lying beneath the skin in preserved 3-day old specimens. The first upper molars have erupted in specimens 7 days old and all cheek teeth are prominent in those 10 days old. The ears are small and obscure at birth. By the ninth day the external ears begin to open; on the tenth day they are definitely open but do not function efficiently until the eleventh day; presumably the auditory canal remains closed until then. Varying lemmings are born with claws on all toes. The pollex is naked and rudimentary. At 25 days of age, animals born in the summer have "summer claws" while those born in the winter have enlarged "bifid" claws on the third and fourth digits of the front feet. The appearance of bifid claws is preceded by an enlargement of the toe pads on the third and fourth digits of the front feet. Young that have bulbous toe pads on these digits at 10 to 14 days of age, will have developed bifid claws at 25 days of age. There was no apparent correlation between coat colour and bifid claws, since all young born in the winter developed bifid claws, although their pelages varied from whitish to reddish.

Behaviour. *One day*: the young can crawl feebly with their front feet; they indiscriminately rest on their belly, sides, or back; vocal sounds are infrequent. *Three days*: the young crawl with difficulty. *Four days*: the young are capable of crawling, mainly with the front feet. *Five days*: the

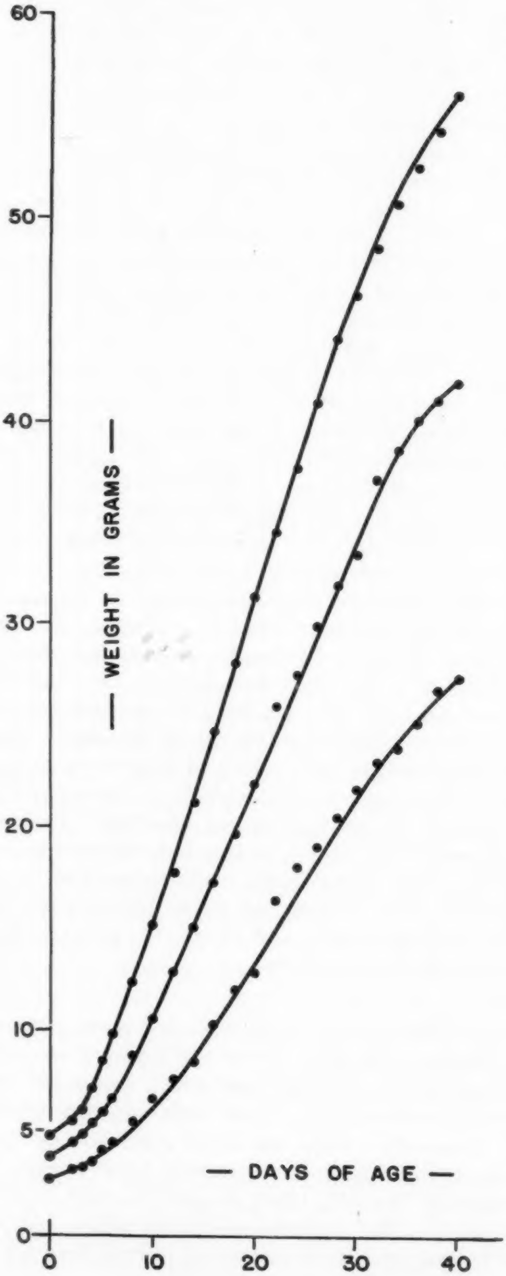


Fig. 3. The averages and extremes in weight of young varying lemmings from shortly after birth to 40 days of age.

young are capable of more complex movements and move their hind legs feebly while crawling; they are able to maintain an unsteady balance and climb an incline. *Seven days*: they crawl rather efficiently on all four feet but remain unsteady in doing so; the submissive response to being picked up by the scruff is present, but not strongly developed. *Ten days*: the submissive response to being picked up by the scruff is strongly developed. *Eleven days*: the young are able to detect sounds, as is shown by the fact that they will often run out of the nest when the nesting box is scratched; they can stand feebly on all four legs. *Twelve days*: the eyes are open and the young travel to all parts of the cage; they are extremely sensitive to sounds and make quick movements in response to loud noises. *Thirteen days*: the young spend more time out of the nesting box; they maintain a steadier balance while walking and can scratch themselves behind the ears with the hind feet. *Fourteen days*: the young eat green plants, rolled oats and other food items when outside the nesting box; behaviouristic traits suggestive of "gentle" fighting and play are discernible; the submissive response to being picked up by the scruff is somewhat reduced and the female no longer returns the young to the nest. *Sixteen days*: the young take food in liberal quantities and the behaviour of the female indicates that the young are being weaned; all young are frequently seen eating together outside of the nest. *Seventeen days*: the young are able to climb on a tread wheel and turn it slowly. *Eighteen days*: the female tries to avoid the young and to prevent them from nursing, although the young frequently pursue the mother and attempt to nurse. *Nineteen days*: the young run on the tread wheel. *Twenty days*: the young attempt to avoid being caught; their defensive attitude, however, is not strongly developed. *Twenty-two days*: the young have a more strongly developed defensive attitude, they click their teeth, utter loud adult-like squeaks and have lost the submissive response when picked up by the scruff. *Twenty-three days*: the young frequently attempt to bite and scratch when being caught; the clicking of their teeth suggests a defensive attitude; young at this age sometimes develop a hierarchy if left together, and the first signs of intense fighting are observed. The young exhibit an "alarm" response and show behaviour that is interpreted as fright. They often run quickly into their nesting boxes when approached or when loud noises are made. *Twenty-five to forty days*: the behaviouristic traits become progressively more adult-like and beyond 30 days of age the behaviour does not differ significantly from that of adults.

Sexual Maturity. The minimum age at which young varying lemmings breed is not accurately known. Manning (1954: 37) reported one female which produced a litter when 84 days old and a male which sired a litter when 46 days old. I have recorded one female which gave birth to a litter when she was 49 days old (20 days gestation). Field data taken from animals trapped at Umiat, Alaska, also indicate that females may naturally breed at early ages. For example, a female weighing 29.3 gm., taken on July 31, 1955, contained five embryos, 5 mm. in length. She possessed immature pelage and when compared with young of known ages she was estimated to have been approxi-

mately 28 to 30 days old. Another female weighing 38.0 gm., taken at the same time at Umiat, contained five embryos, 4 mm. in length. This animal was in the process of acquiring its subadult pelage and was estimated to have been 34 days old. Examination of captive young showed that the vagina remains imperforate until the young attain an age of 25 to 27 days. At this age the vagina becomes swollen and perforate. According to these data females are apparently capable of copulating and producing gametes when 25 to 30 days old.

The loss of the pubic symphysis and formation of a "gap" do not appear to take place in varying lemmings as it does in pocket gophers. Hisaw (1924) reported absorption of the symphysis to take place in the gopher before copulation (p. 94), and found no evidence to indicate that the symphysis is restored after parturition. I have not observed the presence of a "gap" in female varying lemmings prior to copulation, and have only noted its presence in pregnant females. Three females which were kept isolated from males developed closed pubes 25 days after parturition. Guilday (1951) stated that in *Microtus pennsylvanicus* "there does not appear to be any evidence of resorption of part of the pubic bones . . . rather there is a lateral movement of both innominates to facilitate parturition". This may also be the way in which the pubic "gap" is formed and lost in varying lemmings.

Growth. Gains in weight of young varying lemmings are shown in Figs. 3 and 4. Morrison *et al.* (1954) described the growth in weight of varying lemmings from birth to 20 days as "a simple, straight line". I found this is not true for larger samples than available to them, but that weights increase in a typical sigmoidal relation with age. The weights of young taken shortly after birth averaged 3.8 gm., with extremes of 2.7 gm. and 4.8 gm. Fig. 3 shows a relatively slow increase in weight to about 4 days of age, at which time the weights range between 3.5 gm. and 7.2 gm. and average approximately 5.4 gm. Between the fifth and twenty-second day, however, weight increases much more rapidly. At 22 days of age the range of variation is from 16.5 gm. to 34.6 gm., and the average approximately 26.0 gm. The rate of increase in weight starts slowing down near the twenty-second day, and the curve tends to begin leveling off near 40 days. At 40 days of age, subadult animals vary in weight from about 28.0 gm. to 56.3 gm., with an average weight of 42.0 gm. As weights increase from birth to 40 days of age there is also an increase in the range of variation. Individuals of the same litter, as well as the composite growths of all litters show increased variation with age (Figs. 3 and 4). Beyond 40 days of age the rate of increase in weight does not slow down as rapidly for smaller animals as it does for larger animals (Fig. 3).

Remarks. Listed in Table 1 are the various ages at which certain developmental features are acquired by the young of some microtines. At Umiat, Alaska, it was not uncommon to take *Microtus oeconomus* and *Clethrionomys rutilus* in the same runways with varying lemmings. The other data are for

microtines from more southern latitudes and varying lemmings from various geographic areas.

According to Table 1, it is apparent that varying lemmings from Umiat develop at about the same rate as *Clethrionomys* and *Lagurus*, slower than *Microtus* and much faster than *Phenacomys*. Specific differences as well as geographic differences in rate of development are shown. For example, *M. oeconomus* develops slower than its more southerly relative *M. pennsylvanicus*; and *M. oregoni* develops slower still. Apparently varying lemmings from Alaska develop faster than those from Greenland although they may develop slower than those from Northern Canada.

Table 1. Comparison of developmental features of some microtines.*

	incisors erupt	*cheek teeth erupt*	*eyes open*	*auditory canals open*	*weaned*
Microtus pennsylvanicus					
(Bailey, 1924)	5	7	about 8	about 8	12
(Hamilton, 1941)	6–7	–	8	8	12–13
Microtus oregoni					
(Svihla, 1932)	–	–	10–11	–	15
(Cowan & Arsenault, 1954)	5½	11½	10–11½	10	13
Microtus oeconomus					
(Morrison *et. al.*, 1954)	9	–	9(–10?)	closed at 9 days	–
Microtus californicus					
(Selle, 1928)	–	–	9–10	–	–
Lagurus curtatus					
(James & Booth, 1954)	–	–	9–13	–	21
Clethrionomys gapperi					
(Benton, 1955)	7–8	–	12–13	–	17
Clethrionomys rutilus					
(Morrison, *et. al.*, 1954)	9	–	10–11	8–9	–
Dicrostonyx groenlandicus					
Greenland (Degerbøl & Møhl–Hansen, 1943)	about 13	–	13–14	–	18
Barter Island, Alaska (Strecker & Morrison, 1952)	8	–	14	closed at 7 days	–
Colony from Umiat	5	7–9	12	11	17
Northern Canada (Manning, 1954)	–	–	–	–	14
Phenacomys longicaudus					
(Howell, 1926)	–	–	19	–	29

*Time in days.

One might expect faster development and higher growth rates in the young of microtines which live successfully in the extremes imposed upon them by the rigorous arctic environment. Both these factors will influence the age at which the young can leave the nest and forage for themselves. However, it is not apparent in these data that microtines living in the arctic have a higher developmental rate than those from farther south. Rather, it seems that the rates of development are inherent characteristics of populations that may be correlated with factors other than climate. In microtine rodents maternal care and behaviour are perhaps more important to survival than rate of growth or development.

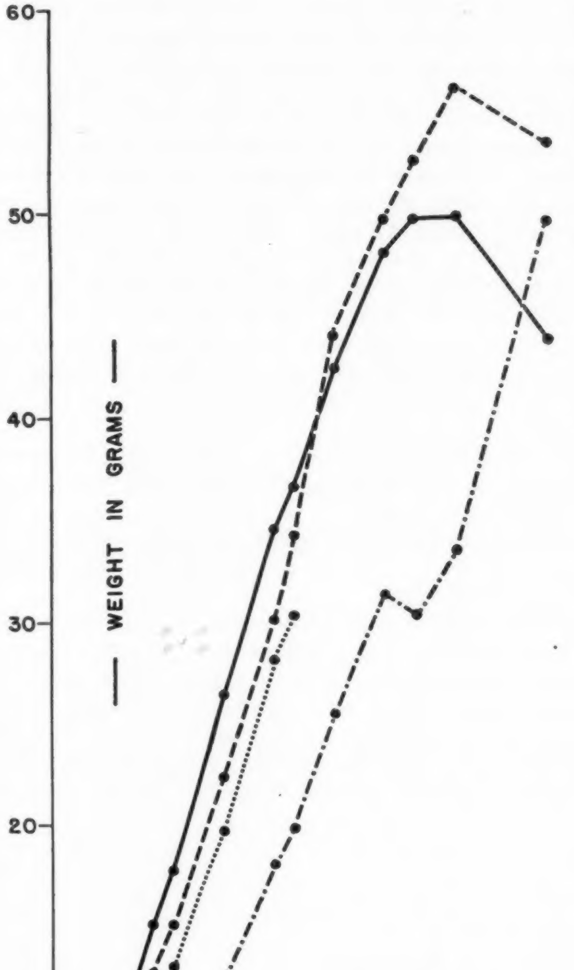


Fig. 4. The individual weight increases for a litter of four from birth to 49 days of age (one died at 27 days of age).

Summary. Growth and development of young varying lemmings (*Dicrostonyx groenlandicus rubricatus*) were studied. The general development of young from the time they were born until they were 40 days old is presented. Young possess bristles on their lips, and vibrissae on the sides of the rostrum at birth. *Four days*: the dorsum becomes covered with short, stiff hair. *Five days*: incisor teeth are prominent. *Six days*: the young crawl on all four feet. *Eight days*: all body surfaces are covered with hair but growth of hair continues until the age of 15 days. *Nine days*: the external ears are open but the ears do not function efficiently before the eleventh day. *Twelve days*: the eyes open and the young wander about the cage. *Fourteen days*: the young eat food other than milk supplied by the mother. *Eighteen days*: the young are completely weaned although they pursue the mother and attempt to nurse. *Twenty days*: the young develop a defensive behaviour. *Twenty-two days*: the young chatter, click their teeth and often bite or scratch when handled. *Twenty-six to thirty days*: short stiff hairs appear on the belly beneath the immature pelage, this is the first indication of subadult pelage. The course of development of subadult pelage is directed dorso-anteriorly.

Sexual maturity is reached in some females at 25 to 30 days of age. At this time they still possess their immature pelage. The vagina becomes perforate in females at 25 to 27 days of age.

The bifid claws of the third and fourth digits of the front feet are present in immature animals born in winter. The bifid claws have not been observed in immatures born during the summer.

At birth, young weigh an average of 3.8 gm. (extremes, 2.7 gm. and 4.8 gm.). Weight increases relatively slowly until 4 days, at which time the young average 5.4 gm. (extremes, 3.5 gm. and 7.2 gm.). The most rapid growth occurs between 5 and 22 days of age. At 22 days the weights average 26.0 gm. (extremes, 16.5 gm. and 34.6 gm.). The rate of increase in weight begins to decline beyond 22 days and tends to start leveling off at 40 days of age. At 40 days weights average 42.0 gm. (extremes, 28.0 and 56.3 gm.).

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INSTITUTE NEWS

Gifts to the library

The Institute library acknowledges with thanks gifts of books and reprints from the following persons and organizations:

Kathleen R. Allington
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Award of Institute research grants

In addition to those listed in *Arctic*, Vol. 10, No. 1, the following have been awarded research grants for field and laboratory investigations by the Institute for 1957 from the Sir Frederick Banting Fund and from funds of the Institute:

ANTHONY, LEO MARK. University of Alaska, College, Alaska.
A study of the effect and nature of seasonal changes upon heavy metal content of certain subarctic streams.

BARRY, THOMAS W. Cornell University, Ithaca, N.Y.
Completion of nesting phase of American brant life history at Southampton Island, N.W.T.

CANTLON, JOHN EDWARD. Michigan State University, East Lansing, Mich.
Studies of differences in abundance and cover of plant species along environmental gradients associated with micro-, meso-, and macro-topographic features in tundra vegetation at Brooks Range, Northern Alaska.

DEAN, FREDERICK C. University of Alaska, College, Alaska.
Study of the grizzly bear.

EINARSEN, ARTHUR S. Oregon State College, Corvallis, Ore.
Study of the black brant (*Branta bernicla nigricans*).

FAY, FRANCIS H. Arctic Health Research Center, Anchorage, Alaska.
Pacific walrus investigations.

FREESE, LEONARD ROY. University of Houston, Houston, Texas.
To complete illustrations and scientific work for a paper on the diatoms of Alaska collected in the vicinity of Point Barrow.

HARPER, FRANCIS. 115 Ridgway Street, Mount Holly, New Jersey.
Investigation of the Ungava cariboo.

LENSINK, CALVIN J. Purdue University, Lafayette, Ind.
A study of the status of the sea otter populations by comparison of the historical and existing populations, and by a comparison of existing populations in areas of varied population density.

WILCE, ROBERT T. University of Michigan, Ann Arbor, Mich.
Study of the marine flora in the Strait of Belle Isle, Newfoundland.

Honorary Member

At the meeting of the Board of Governors in New York on June 15, 1957, Captain EINAR MIKKELSEN, Vilhelmshaabsvej 6, Charlottenlund, Denmark, fellow of the Institute, was designated an Honorary Member of the Arctic Institute of North America.

NORTHERN NEWS

Greenland today

While in summing up the average person's knowledge of Denmark one might list many things, it is probable that most of them would be associated with the idea of a small, flat country, with pleasant scenery and a congenial climate, whose inhabitants live by farming and brewing. Yet it is a fact that 98 per cent of the territory is one of the wildest and most desolate mountain regions in the world with glaciers nearly half the size of western Europe. For Greenland forms an integral part of the Danish kingdom, and its area of 780,000 square miles is about fifty times that of the rest of Denmark put together. If it makes a smaller impression in the minds of most people, that is because it is inhabited by only about 25,000 persons, or approximately 0.5 per cent of the total population of Denmark.

Greenland is the largest island in the world, measuring from south to north more than 1,500 miles, but five-sixths of the area is covered by the vast ice-cap, which has a thickness of up to 10,000 feet. Only a narrow coastal fringe is ice-free, and even there arctic conditions prevail and forests are non-existent. The ice-free area is a mountainous region intersected by great fiords and reaching a height, in Gunnbjørns Fjeld, of 12,400 feet, the highest point inside the Arctic Circle. Glaciers coming from the ice-cap at many points pack the deep fiords with gigantic icebergs. The grandeur of the scenery is scarcely equalled anywhere in the world, and many districts of Greenland undoubtedly offer great opportunities for future tourist travel.

The 25,000 Greenlanders who inhabit the coasts, in particular the southern part of the west coast, are of mixed Eskimo and Scandinavian extraction. The connection between Greenland and Scandinavia goes back a thousand years to the time of the Vikings, when the great voyages of discovery of these hardy seamen took them across the North Atlantic via Greenland to North America, 500 years before Columbus discovered the Bahamas. The Greenlanders now all belong to the national Lutheran Church of Denmark, and in every respect enjoy equal status with other members of the Danish population.

Politically, Greenland constitutes a part of the Danish democracy. Popularly elected local councils administer local affairs, and two Greenlanders, elected in Greenland, sit in the Folketing, the Danish Parliament. Together with the 177 other members, they legislate in matters affecting the kingdom as a whole, including Greenland.

The economy of Greenland is based primarily on the sea. The land offers few facilities for economic development. Forests, as already mentioned, are non-existent, and farming is restricted to sheep-rearing in a few of the well-sheltered fiords in the extreme south of West Greenland. But the sea has ample resources and it is from there that the population of Greenland, and indeed the populations of all the regions peopled originally by Eskimo, have always got their living. The primitive economy was originally founded on seal-hunting, but the change in world climate, which has taken place during the last generation has forced the Greenlanders to reorganize their economic life as the seal vanished from southern Greenland waters and fish appeared to take its place. Fishing, especially cod-fishing, has undergone a great expansion during the last thirty years. Greenland is now the home of a modern fishing and fish-processing industry competing with the best in the world market.

If the soil of Greenland affords little facility for agriculture and forestry, it

contains minerals, which have proved capable of economic extraction and, it is hoped, will continue to do so in the future. For nearly a hundred years the mineral cryolite, the bulk of which is used in the aluminium industry, has been mined at Ivigtut, in southwest Greenland. This, incidentally, is the only place in the world where it can be economically worked. At Mesters Vig, in northeast Greenland, the mining of zinc and lead was recently started. It is an enterprise that seems to offer the prospect of profitable working, but which in particular is expected to form the basis for future prospecting of a larger area with interesting possibilities of mineral finds. Since the war, an intensive geological survey of the whole of Greenland has been undertaken with such possibilities in view.

Greenland is remarkable for, among other things, the fact that there is no income tax—not yet! But there is other taxation, especially on spirits, tobacco, and various other luxuries. The revenue from these taxes goes to the local councils, which spend the bulk of it on social welfare, especially the care of the aged, invalids, orphans, etc. Social welfare, in other words, is provided by the local inhabitants. On the other hand, the Danish Government has assumed responsibility for the health services. The climate, and the poor housing that still exists in many places have meant that the health conditions in the past have not been good. Tuberculosis, in particular, has always been a scourge. The Danish Government operates some fifteen hospitals in Greenland, staffed by doctors and nurses. Medical care, medicines, and hospitalization are free to the entire population. Recently, a modern sanatorium, Queen Ingrid's Sanatorium at Godthaab, the capital, with 21 beds, was opened, and another major weapon in the war on tuberculosis was also brought into action recently, when the ship *Misigssut* went into operation. This ship is equipped with every means known to science for the detection of tuberculosis. It travels up and down the several thousand miles of coast and has already called at all the hundreds of small settlements and examined practically every Greenlander. It is hoped to reduce the incidence of tuberculosis by these means, in a relatively short period of time, to the level of the rest of Denmark, which is the lowest in the world. An important associated factor is the drive to raise the housing standard by means of cheap loans, Government grants, and technical assistance in building.

The work of educating the people of Greenland began over two hundred years ago and it is a hundred years since illiteracy was abolished. The system of education has been greatly extended in recent years and it is now possible to pass from schools in Greenland with examinations that are the equivalent of those elsewhere in Denmark. Educational work is greatly hampered by language difficulties, as the bulk of the population speaks only the Eskimo language. A great effort is now being made to make the people bilingual through the teaching of Danish, while education in the speaking and writing of their own language is being intensified as never before.

Altogether, there is at present a great deal of activity in adult education; libraries, evening classes, and study groups have been opened in many places. It is planned to set up a folk high school on the same lines as the famous Danish folk high schools, a project that is expected to yield good results.

The radio, in particular, is an important factor in adult education. The immense size of the country has been something of an obstacle, but with the extension of the broadcasting net work, which is expected to reach completion in the spring of 1958, there will be full coverage and it will be possible by this educational medium, so admirably adapted to Greenland conditions, to penetrate to every one of the thousands of widely scattered homes. Incidentally, the Greenland broadcasting stations, which transmit chiefly in the Eskimo language, can be heard by the Eskimo of northern Canada, who speak the same language.

The geographical situation of Greenland has given it increased topicality in

recent years. In the old days when world communications lay across the oceans, Greenland was remote, the northern waters being difficult to navigate owing to the climate and the ice. The rise of inter-continental air travel has basically altered the relative position of Greenland and it is now situated practically midway between Europe and North America where most of the world's economic activity is located. A glance at the globe will show that many of the shortest routes between these two continents lie across Greenland. Greenland will therefore in the future acquire a greatly enhanced importance, which will confront Denmark with problems of assisting air traffic by means of airfields, meteorological stations, and air safety service. Already a large meteorological network has been established, financed chiefly by the International Civil Aviation Organization, and air routes between northern Europe and the west coast of the United States now pass through airports in Greenland.

Greenland's relationship to Denmark in the past was that of a colony, it is only in our own time that it has become an integral part of the kingdom. But it would be wrong to infer that it was ever exploited by Denmark. On the contrary, Denmark always considered its task to be that of assisting the population to achieve the same level of civilization as that of other Danes. In a period that has seen the breaking-up of great colonial empires and the attaining of independence by former colonies, the opposite development has taken place in Greenland: a former colony has been integrated into the kingdom. The policy that has led to this result will also be applied in the future, the ties that bind Greenland and Denmark together being made firmer and closer.

Eske Brun

IX International Botanical Congress

The Ninth International Botanical Congress will be held in Montreal, Canada, from August 19 to 29, 1959, at McGill University and the University of Montreal. The program will include papers and symposia related to all branches of pure and applied botany. A first circular giving information on program, accommodation, excursions, and other detail will be available early in 1958. This circular and subsequent circulars including application forms will be sent only to those who ask to be placed on the Congress mailing list by writing to the Secretary-General:

Dr. C. Frankton
Secretary-General
IX International Botanical Congress
Science Service Building
Ottawa, Ontario
Canada.

The cache at Victoria Harbour

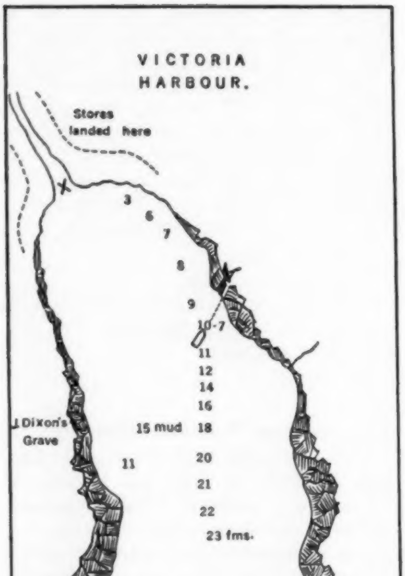
This was established by Captain John Ross on May 28, 1832, just before the *Victory* was abandoned. In a "tunnel", the long and troublesome excavation of which is described in Chapter 48 of his "Narrative"[1], he deposited the following valuable scientific instruments: one 36-inch transit, one 9-inch theodolite, one 3½-inch astronomical telescope, 5 feet 6 inches long, four chronometers, and also some gunpowder.

Unfortunately, he never recorded the whereabouts of the tunnel! Neither did his malcontent steward William Light, in the book he inspired, although his account[2] stated that the excavation was given the semblance of a grave by placing atop it two human skulls (filched from Eskimo graves at Felix Harbour). I suggest, however, that his account is unreliable, as Captain Ross used the word "tunnel" on three different occasions; the steward probably confused the grave prepared for the man who died while the tunnel was being excavated.

There are, however, two clues to the position of the cache, afforded by illustrations in the "Narrative". Opposite page 608 is a plan of Victory Harbour. This long and narrow, mountain-girt

[1]Ross, Sir John. Narrative of a second voyage in search of a northwest passage. . . London, 1835. p. xiii.

[2]Huish, Robert. The last voyage of Captain John Ross R.N. . . . London, 1835. p. 619.



harbour has a large stream entering it at its inner or northwest end. A point "X" half-way across the mouth of this stream has been taken for computing the measurements that follow. The plan shows:

"J. Dixon's grave" on the west bank, app. 750 yards (direct) from X;

"Stores landed here" at the north end, on a slope above the east bank of the stream;

the *Victory* in 10 fathoms water, fairly close in to the east shore and app. 650 yards from X;

a masted sloop, the *Victory's* tiny consort *Krusenstern*, hauled high and dry on the east side of the harbour 600 yards from X; just to the south of her appears to be a slope to the water's edge;

a dashed line from the bows of the *Victory* to a spot at the foot of that slope and 625 yards from X.

The stores referred to were articles of wood, iron, canvas, and rope, which Captain Ross left strewn about for the benefit of the natives, and some remains of which were found by Superintendent Larsen in 1942[3] and have since been photographed by Richard Harrington[4].

It is the dashed line that is so fascinating. Although rather faint to the naked eye, under a magnifying glass it appears firm and clear. It must have some meaning, and may well indicate the direction of the cache; for what other significance could it have?

That the tunnel was in fairly close proximity to both the *Victory* and the *Krusenstern* is deducible from the fact that one and the same sentence in the "Narrative"[5] recorded the concealment of the instruments "in the place that we had made" and the placing of the masts, sails, and rigging of the *Victory* ashore by the little sloop.

As to its precise whereabouts—a hint may be offered by the frontispiece. This, styled "Victory Harbour", shows the *Victory* in the centre background. in the right foreground are two figures, an officer and a seaman, the former holding a chain or fuse, the latter wielding a long pole. Behind them is a vertical spar, probably the mast of the *Krusenstern.* Admittedly, the object from which it protrudes looks more like a loaded sledge than a boat, but as all the spare provisions were placed inside the hull of the *Krusenstern,* this presumably would have been covered with canvas to protect them from the weather. It is therefore possible that the frontispiece illustrates a step in the construction of the tunnel.

Of course, after 125 years it is more than possible that the site of the tunnel has been obliterated by landslides, but a

[3]Larsen, Henry. The conquest of the north west passage. . . . Geog. J. 1947. 110: 7.

[4]Harrington, Richard. The face of the Arctic. New York, 1953, opp. p. 152.

[5]*loc. cit.,* p. 643.

skull has been found by an R.C.M.P. patrol from Spence Bay[6] on the opposite side of the harbour, close to the mapped position of J. Dixon's grave, it may still be worth the while of any future visitors to Victoria Harbour to look on the eastern side of the harbour for John Ross's cache. The slope up which the *Krusenstern* was hauled may still be possible of identification, particularly if it is borne in mind that she was a decked vessel of sixteen tons burden[7]—a tough proposition for only twenty men to pull up a hill-side even if aided by tackle. The slope must have been quite a gentle one, a valley amongst the craggy surrounds of Victory Harbour—in fact, like the one depicted in the frontispiece.

NOEL WRIGHT

[6]Royal Canadian Mounted Police, unpublished report.

[7]*loc. cit.*, p. 7.

GEOGRAPHICAL NAMES IN THE CANADIAN NORTH

The Canadian Board on Geographical Names has adopted the following names and name changes for official use in the Northwest Territories and Yukon Territory. For convenience of reference the names are listed according to the maps on which they appear. The latitudes and longitudes given are approximate only.

Mayo, 105M
(Adopted December 6, 1956)

Trail Creek	63°48'N.	135°49'W.	
Aldis Creek	63°50'	135°48'	
Fortune Creek	63°51'	135°46'	
Bighorn Creek	63°54'	136°58'	
Spire Creek	63°55'	135°53'	
North Star Creek	63°55'	135°50'	
Youth Creek	63°52'	135°46'	
Snowshoe Creek	63°59'	135°51'	
Shanghai Creek	63°55'	135°42'	
Field Hill	63°49'	135°42'	
Black Creek	63°49'	135°48'	not Halfway Creek
Van Cleaves Hill	63°49'	135°33'	not Vankleek Hill

Hill Island Lake, 75C
(Adopted December 6, 1956)

Lenson Lakes	60°01'N.	109°41'W.
Quinnell Lake	60°01'	109°39'
Dominas Lake	60°01'	109°33'
Chalus Lake	60°01'	109°28'
Holyoak Lake	60°01'	109°23'
Portman Lake	60°02'	109°13'
Prescott Lake	60°01'	109°07'
Kimber Lakes	60°01'	108°22'
Dalgliesh Lake	60°01'	108°58'
Paradis Lake	60°01'	108°09'
Larance Lake	60°01'	108°13'

Abitau Lake, 75B
(Adopted December 6, 1956)

Ledingham Lake	60°01'N.	107°49'W.
Huntington Lake	60°01'	107°40'
Gifford Lake	60°01'	107°29'

Dinnie Lake	60°01′	107°08′	
Renaud Lake	60°01′	107°04′	
Chesney Lake	60°01′	106°54′	
Birban Lake	60°01′	106°43′	
Bohonis Lakes	60°01′	106°34′	

Byam Channel, 78 NW and 78 NE
(Adopted December 6, 1956)

Tingmisut Lake	75°56′N.	107°53′W.

Greely Fiord 49A (S 1/2) and 39A (S 1/2)
(Adopted December 6, 1956)

Hot Weather Creek	80°13′N.	84°45′W.

Nansen Sound, 69A (S 1/2) and 59A (S 1/2)
(Adopted December 6, 1956)

Wading River	80°32′N.	95°25′W.	
Bunde River	80°33′	93°30′	
Blizzard River	80°36′	93°42′	
Bukken River	80°43′	93°40′	
Lightfoot River	80°44′	90°45′	
Camp Five Creek	80°32′	94°15′	not Basalt Creek

Craig Harbour, 49 SW and 49 SE
(Adopted December 6, 1956)

Grise Fiord (post office)	76°25′N.	83°01′W.
Meadow River	77°53′	82°36′

Wholdaia Lake, 75 SE
(Adopted December 6, 1956)

McLaren Lake	60°01′N.	105°45′W.
Neufeld Lake	60°01′	105°30′
Brophy Lake	60°01′	105°23′
Cheropita Lake	60°01′	105°20′
Hans Lake	60°00′	105°18′
Lacusta Lake	60°02′	105°12′
Durk Lake	60°01′	105°09′

Kazan River, 65 SW
(Adopted December 6, 1956)

Cote Lake	60°01′N.	103°48′W.
Korol Lake	60°01′	103°42′
Bradford Lake	60°02′	103°06′
Danforth Lakes	60°01′	102°53′
Cayen Lake	60°02′	102°34′
McQuillin Lakes	60°01′	102°26′
Sarka Lake	60°00′	102°24′
Jasin Lake	60°01′	102°23′

Sverdrup Islands, 69 (N 1/2) and 59 (N 1/2)
(Adopted December 6, 1956)

Amarok River	79°02′N.	92°45′W.
Surprise Fiord	78°15′	91°10′
Strand Fiord Pass	79°05′	90°00′
Temperance Bay	78°07′	98°35′
Slime Peninsula	78°02′	98°25′
Stratigrapher River	78°42′	96°50′
Geologist Bay	78°37′	96°05′
Structural River	78°25′	95°55′
Hoodoo River	78°22′	99°50′

Divergent River	78°27′	99°55′	
Contour River	78°43′	100°00′	
Dumbbells Dome (hill)	78°40′	101°20′	
Haakon River	78°43′	101°15′	
Isachsen Dome (hill)	78°28′	102°15′	
Transection River	78°14′	101°52′	
Buchanan Lake	79°28′	88°35′	not Maersk Lake nor Diana Lake nor Landing Lake
Meteorologist Peninsula	78°03′	100°00′	not Thomson Peninsula
Helicopter Bay	78°43′	99°50′	not Sikorsky Bay
Malloch Dome (hill)	78°15′	101°35′	not Okanagan Dome (hill)

Bache Peninsula, 49 (N 1/2) and 39 (N 1/2)
(Adopted December 6, 1956)

Starfish Bay	75°08′N.	85°10′W.

Barrow Strait West, 68 NW and 68 NE
(Adopted December 6, 1956)

Crying Fox Creek	75°35′N.	99°53′W.
Caledonian River	75°35′	99°14′
Variscan River	75°33′	99°46′

Norwegian Bay, 59 SW and 59 SE
(Adopted December 6, 1956)

Paradise River	77°48′N.	92°55′W.
Nicolay Lake	77°48′	94°49′
Ensorcellement River	76°55′	94°20′
Rancher River	77°21′	90°55′

Somerset Island, 58 SW and 58 SE
(Adopted December 6, 1956)

North Elwin River	73°33′N.	90°58′W.	
Hunting River	73°39′	94°50′	
West Cresswell River	72°53′	93°28′	
East Creswell River	72°48′	93°20′	
Batty River	73°14′	91°35′	
Cunningham River	74°00′	93°37′	
Garnier River	73°58′	92°15′	
Aston River	73°40′	94°34′	
Elwin River	73°34′	90°59′	not South Elwin River
Cresswell River	72°48′	93°30′	not North Cresswell River

King Christian Island, 69 SW and 69 SE
(Adopted December 6, 1956)

Fog Bay	77°55′N.	97°05′W.	
Twilight Creek	76°14′	99°10′	
Stuart River	76°12′	99°28′	
Cut Through Creek	76°13′	99°05′	not Cutthrough Creek
Bent Horn Creek	76°19′	103°50′	not Benthorn Creek

Larsen Creek, 116A
(Adopted December 6, 1956)

Lake Creek	64°38′N.	137°10′W.

Aishihik Lake, 115 H/6
(Adopted December 6, 1956)

Borthwick Lake	61°28′N.	137°27′W.
Houghton Lake	61°21′	137°21′
Lacelle Lake	61°23′	137°01′

Decourcy Lake	61°29′	137°09′
Mount Creeden	61°16′	137°15′
Lister Creek	61°27′	137°12′

Fort Liard, 95B
(Adopted December 6, 1956)

Beaver Water Creek	60°58′N.	123°30′W.
Big Island Creek	60°03′	123°30′
Blue Bill Creek	60°51′	123°36′
Rabbit Creek	60°27′	123°25′
Betalamea Lake	60°07′	123°34′
Mount Coty	60°18′	123°32′
Netla (settlement)	60°55′	123°15′
Big Island	60°28′	123°30′

Kazan River, 65 SW
(Adopted January 17, 1957)

Bourassa Lake	60°15′N.	102°56′W.

Beaverhill Lake, 57 I
(Adopted January 17, 1957)

Croft Lake	62°07′N.	104°13′W.	
Scheelar Lake	62°03′	104°43′	
Biblowitz Lake	62°14′	105°12′	
Logie Lake	62°08′	105°47′	
Snelgrove Lake	62°20′	105°37′	
Nieznany Lake	62°23′	105°10′	
Mossip Bay	62°43′	104°19′	
Noyes Lake	62°33′	105°55′	
Bodie Lake	62°58′	105°52′	
Olson Lake	62°55′	105°17′	
Beck Lake	62°51′	104°37′	
Shoemaker Lake	62°24′	104°18′	not Peterson Lake
Breithaupt Lake	62°38′	105°25′	not Price Lake

Lynx Lake, 75J
(Adopted January 17, 1957)

Catholic Lake	62°37′N.	107°18′W.	
Sled Lake	62°08′	106°48′	
Huff Lake	62°17′	107°10′	
Timberhill Lake	62°23′	106°38′	
McFarlane Lake	62°41′	106°13′	
LaRoque Bay	62°32′	106°54′	
Blake Lake	62°07′	106°27′	not Nelson Lake

Marian River, 85N
(Adopted March 7, 1957)

Treasure Lake	63°30′N.	116°35′W.
Maryleer Lake	63°28′	116°32′
Sherman Lake	63°27′	116°31′
Myrt Lake	63°19′	116°51′
Sheldon Lake	63°18′	116°48′
Nec Lake	63°17′	116°53′

Cumberland Sound, 26 SW and 26 SE
(Adopted March 7, 1957)

Tesseralik (settlement)	65°56′N.	65°57′W.
Kekerten (settlement)	65°42′	65°49′
Shakshukowshee Island	65°17′	66°54′
Shakshukuk Island	65°15′	66°50′

Chidliak Point	65°02′	66°39′	
Tawsig Fiord	64°50′	65°48′	
Misty Island	64°07′	65°03′	
Okalik Island	64°06′	64°56′	
Vivi Harbour	64°00′	64°45′	
Maktaktujanak Island	65°14′	66°45′	
Akuna Point	65°11′	66°45′	
Angiyok Island	65°45′	65°50′	
Akulagog Island	65°43′	65°51′	
Tuatait Islands	65°50′	65°51′	
Name changes			
Opingivik (settlement)	65°15′	67°03′	not Opungnivik (settlement)
Kipisa (settlement)	65°12′	66°57′	not Krepeshaw (settlement)
Utusivik (settlement)	65°05′	66°37′	not Kimiksuit (settlement)
Kingmiksok (settlement)	65°05′	66°43′	not Kimiksuit (settlement)
Kaigosuiyat Islands	65°43′	67°18′	not Kairosueyet Islands
Kaigosuit Islands	65°47′	67°33′	not Kairosuet Islands
Kudjak Island	65°37′	67°14′	not Cudjak Island
Ikpit Bay	65°22′	67°15′	not Ikpite Bay
Aupaluktut Island	65°24′	66°50′	not Awpaluktoot Island
Kangigutsak Island	65°12′	66°48′	not Ahkodnona Island
Kikiktaluk Island	64°55′	66°10′	not Kekertdjaluk Island
Sulut Bay	64°45′	65°41′	not Shoodlood Bay
Ugjuk Island	64°41′	65°30′	not Ujuk Island
Tupiuyak Island	64°02′	64°21′	not Toopik Island
Okalik Bay	64°03′	64°55′	not Okalier Bay
Name confirmations			
Kekertar Island	65°57′	67°07′	not Eevesha Island nor Ivisa Island
Audnerbing Bay	65°54′	67°20′	not Aunervik Bay nor Auniakvik Bay
Kekertuk Island	65°53′	65°35′	not Kerkertukdjuak Island nor Kekertukdjuak Island
Kikastan Islands	65°42′	65°50′	not Kekerten Islands
Ugjuktung Fiord	65°15′	64°25′	not Ujuktuk Fiord
Kaxodluin Island	64°49′	65°30′	not Kacudluit Island nor Kakodluit Island

Hanbury, 75P
(Adopted March 7, 1957)

Axecut Lake	63°53′N.	104°08′W.	
Downtree Lake	63°46′	104°26′	

MacKay Lake, 75M
(Adopted March 7, 1957)

Snap Lake	63°35′N.	110°51′W.	not Lens Lake

Carcross, 105 D/2
(Adopted March 7, 1957)

Wynton Creek	60°00′N.	134°40′W.	not Racine Creek

Ogilvie Range, 106 SW and 106 SE
(Adopted March 7, 1957)

Cranswick River	66°04′N.	132°08′W.	not West Fork (river) nor Mountain River

Kennedy Channel, 29A (S 1/2), 19A (S 1/2), and 9A (S 1/2)
(Adopted March 7, 1957)

Name confirmation

Lake Hazen	81°50′N.	70°25′W.	not Hazen Lake

Nettilling Lake, 26 NW and 26 NE
(Adopted March 7, 1957)

Avataktoo (settlement)	66°15′N.	66°18′W.	
Ranger River	66°38′	67°32′	
False Passage Peninsula	66°29′	67°49′	
Clear Passage Island	66°24′	67°38′	
Name changes			
Iglungayut (settlement)	66°15′	67°07′	not Bon Accord (settlement)
Usualuk (settlement)	66°15′	66°32′	not Ushualuk (settlement)
Sanigut Islands	66°10′	66°20′	not Shenneroot Islands
Aupaluktok Island	66°09′	66°18′	not Augpalugtung Island
Kolik River	66°10′	65°47′	not Coulee River
Name confirmations			
Millut Bay	66°35′	67°35′	not Milluit Bay nor Milugialik Bay
Clearwater Fiord	66°33′	67°25′	not Kingwa Fiord nor Isuitok Fiord
Sirmilling Bay	66°34′	67°18′	not Shilmilik Bay
Kangilo Fiord	66°20′	67°35′	not Kangjuktuk Fiord nor Imiuk Fiord
Kekertelung Island	66°22′	66°45′	not Kekertalak Island nor Kikiktaluk Island
Usualung Mountain	66°17′	66°25′	not Ushualuk Mountain nor Usualuk Mountain

Markham Inlet, 29A (N 1/2), 19A (N 1/2), and 9A (N 1/2)
(Adopted March 7, 1957)

Name confirmation			
Clements Markham Inlet	82°47′N.	67°30°W.	not Markham Inlet nor Markham Fiord

Cambridge Bay, 77 SW and 77 SE
(Adopted March 7, 1957)

Starvation Cove	69°08′N.	105°57′W.	
Cape Enterprise	69°11′	106°22′	
Long Lake	69°06′	104°30′	
Flagstaff Point	69°04′	105°07′	
Mount Lady Pelly	69°21′	104°55′	
Kitiga Lake	69°15′	105°37′	
Freshwater Creek	69°08′	104°59′	
Simpson Rock	69°03′	105°07′	
Mount Pelly	69°11′	104°40′	
West Arm	69°06′	105°05′	
Jago Islet	69°03′	104°58′	
Augusta Hills	69°08′	105°25′	
Ferguson Lake	60°27′	105°12′	not Tahiryuak (Big Lake) nor Ekalluktok Lake
Name confirmation			
Ekalluk River	69°25′	105°12′	not Ikaluktok River nor Ekalluktok River
Deletion			
Mount Augustus	69°08′	105°25′	

Nash Creek, 106D
(Adopted March 7, 1957)

Name confirmation			
Sluice Creek	64°10′N.	136°00′W.	not Sluice Fork Creek